THE AIR BRAKE

AS RELATED TO

PROGRESS IN LOCOMOTION

AND OTHER PAPERS

INTRODUCTION TO THE STUDY OF AIR BRAKES

BY

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E.V.

INTRODUCTION TO THE STUDY OF AIR BRAKES.

The usual method of commencing the study of the air brake as a whole, or of any of the devices which it comprises is to learn first the location and relation of the different chambers and passageways of the individual devices involved and the various inter-connections which are made according to the different positions of the moving parts of the various mechanisms. All of this is well enough in its proper place, but it is a study of effect rather than cause—of results rather than principles; and the writer is more concerned with the principles and laws underlying the operation of the automatic air brake being understood than that the construction or detailed operation of any particular apparatus be committed to memory. If the laws and principles governing the operation of pneumatic brake mechanisms are mastered at the outset, so that they are thoroughly understood, they can then be intelligently applied to any device or combination of devices which may have to be dealt with and the purposes, functions and merits of the apparatus can be clearly judged.

It is, therefore, the purpose of the author to go somewhat into detail in describing the "Air Brake" as a mechanical device for accomplishing certain ends according to the operation of certain well defined principles. Its operation will be explained in a different way doubtless from what has heretofore been attempted, but by this method of treating the subject it is believed that much of the difficulty heretofore experienced in obtaining a knowledge of the air brake will be removed.

If the student will sub-divide his consideration of the air brake into the following, viz.:

WHAT IT IS	(The mechanical parts of the apparatus)
WHAT IT DOES	(Controls the speed of trains)
HOW IT DOES IT	(By the movement of its parts and development of friction)
WHY IT DOES IT	(Physical laws governing its operation)
HOW TO DO IT	(Manipulation)
AND THE RESULTS	(Good, bad or indifferent, according to its condition, and the knowledge and judgment used in its manipulation),

he will find his task much more easily and quickly accomplished.

The air brake consists of a self-contained or closed system of receptacles and moving parts, and when in working order is charged with compressed air. Its operation is caused by opening and closing the main circuit of the system to the atmosphere, which produces a difference and equalization of the pressures in the system, that is, a difference in pressure causes the brake to apply or release and an equalization or balance of pressure causes it to remain released or to remain applied, and it makes

no difference how these variations are brought about, whether by human agency or any other cause, the effect is the same, and, obviously if the brake is to be automatic in its action (operated by the opening of the system) this must be the case.

The fundamental automatic air brake system forming the elemental unit consists of: First, a compressor; 2nd, a brake pipe with closed ends; 3rd, a triple valve; 4th, a reservoir; 5th, a brake cylinder; 6th, mechanical connection between brake cylinder and brake shoe; and 7th, a brake shoe; the operating power being compressed air. To serve practical purposes, however, it is necessary on at least one vehicle to add a storage reservoir and an operating valve and on all vehicles a system of compound levers.

From the compressor is a pipe (called the brake pipe) leading to a reservoir (called an auxiliary reservoir); in the pipe leading to the reservoir is a valve device (called a triple valve), having a moveable partition or piston and a slide valve which controls ports to and from the reservoir and brake cylinder, and to the atmosphere. The piston divides, except to a limited extent, the air of the brake pipe from the air of the reservoir, thus permitting the pressure relation of these volumes to be changed. The reservoir contains the air that, when it is desired, passes to the brake cylinder forcing out its piston, thus moving the system of levers and exerting the power that applies the brake; the whole process of applying and releasing the brake being brought about by reducing and increasing the brake pipe pressure, thus causing the movements of the piston and slide valve above referred to. In the pipe between the compressor and the valve device is located a valve (called a brake valve) which is operated manually, and, when moved to one position (called release position) permits the air from the compressor to flow to the brake pipe and force the piston of the triple valve to release position, charging the reservoir. When moved to another position (called application position), this valve permits of the brake pipe being opened to the atmosphere, thereby reducing the pressure on the brake pipe side of the piston of the triple valve, so that the then higher pressure in the reservoir can push the piston, which can move a short distance before it moves the slide valve, toward the brake pipe, closing the limited communication between brake pipe and reservoir. Then, having come in contact with the slide valve, it drags it along until the outlet from the brake cylinder to the atmosphere is closed and a passage opened from the reservoir to the brake cylinder. As the air will now reduce equally, and at the same rate, on each side of the piston, until the reduction in the brake pipe ceases or until the air in the reservoir and cylinder reach equal pressures, the piston and slide valve will remain stationary. In the event of the reduction in the brake pipe being made short of the equalizing point of the reservoir and the brake cylinder (by using the lap position hereinafter mentioned), the piston will return in the direction of release and by means of a small valve (called a graduating valve) which is attached to the piston and moves with it, closes the port from the reservoir to the brake cylinder, thus stopping the flow of air. This movement takes place because when the outlet from the brake pipe to the atmosphere was closed the still open ports from the reservoir to the brake cylinder

permitted the reservoir pressure to fall slightly below that of the brake pipe, the higher pressure then moving the piston toward the lower pressure. The reason the piston does not make its full traverse toward release position is because the friction of the slide valve makes it a resistance block, which the slight difference of the pressure required to move the piston only cannot overcome. Therefore, when the piston comes in contact with the slide valve, it is stopped and remains in that position until the balance of pressure is destroyed when it will move again, and of course in the direction of the lowest pressure; thus it will be seen that either a full or partial application of the brakes can be made.

The brake valve has still another position (called lap position) and when the valve is moved to this position all ports are closed, that is, there is no communication from the compressor to the brake pipe nor from the brake pipe to the atmosphere; this position of the brake valve is to be used only when the brakes have been applied and it is desired to hold them applied, for, obviously, the increase of pressure necessary to release the brake or the further decrease in brake pipe pressure necessary to further apply the brake will not take place at this point as long as the valve is in this position.

The brake is released by increasing the pressure in the brake pipe above that of the reservoir, by admitting more air to it through the brake valve, thus forcing the triple valve position and slide valve to release position which opens a passage from the brake cylinder to the atmosphere; or, if the car is detached from the source of pressure, by exhausting the air from the auxiliary reservoir and brake cylinder, means being provided for this purpose.

All the things mentioned in the foregoing must be present in an automatic air brake system, and it is not complete or operative if any one be absent; in practice, however, other parts or accessories are added for many reasons that will be apparent as the reader becomes familiar with the elements of the brake system and the many conditions to be met, but which it is not proper to incorporate here, as this article is intended only to deal with the essentials and not the modifiers of the system.

So far we have considered only the smallest number of parts in an air brake unit and while no matter how many times some of these parts are duplicated, as, for instance, a train of 100 vehicles as compared with a train of two vehicles, the cause of operation remains the same, yet the addition of each part or car makes more difficult the producing of the cause of the operation of the air brake, namely, the difference of pressure between the brake pipe and reservoir essential to its application and release. The reason why it becomes difficult is because the volume of air to be changed in pressure increases so that when the train consists of, say, fifty cars, the volume of the system is increased tremendously as compared with a train of, say, five cars. Therefore, the reduction in pressure takes place so slowly that a difference in pressure between the brake pipe and reservoir is more difficult to obtain, for, while the partition which divides these volumes may fulfill its purpose effectively with a fairly rapid change of pressures, it may fail altogether where the change takes place very slowly, and in any event, the application of the brake, where the number of parts that go to make up the unit is great,

becomes very slow because the pressure cannot flow to the cylinder at a more rapid rate than the brake pipe pressure is being reduced and, of course, the release of the brake (considering it as one) becomes slower with a long train than with a short one. It is this failure to take into consideration the time element in air brake operations that leads to so much improper manipulation and to so many misconceptions regarding it.

If in the application of the principles which govern the design and operation of the air brake, the student will bear in mind that there can be no effect without a cause, the greatest difficulty in understanding not only why the brake operates, but also why at times irregular operations take place would be removed, and what follows is intended to illustrate this.

Thus, the cause of a brake applying is not, strictly speaking, a reduction in pressure, but the producing of a lower pressure in the brake pipe than that of the reservoir which moves the triple piston and slide valve; if this difference in pressure does not occur there can be no movement of the operating parts; and, conversely, it is not an increase in pressure, strictly speaking, that releases the brake, but an increase of brake pipe pressure above the reservoir which resists the movement of the triple piston toward release position, therefore, if there is any condition which prevents the attainment of this difference in pressure between the two vital volumes concerned, namely, brake pipe and reservoir, the movement of the triple piston will not take place, that is, the brake in the one case will not apply and in the other will not release. As an example of what is meant: if the air can feed back from the auxiliary reservoir, through the feed groove or by a loose or stuck packing ring, to the brake pipe at the same rate as the brake pipe pressure is being reduced, the brake will not apply. If when the brake is applied, in attempting to release it by increasing the pressure in the brake pipe, the reservoir pressure rises at the same rate, which may happen in the event of a loose or stuck packing ring or worn piston cylinder bush, the triple piston will not move to release position and consequently the brake will not release. In other words, the operations of the brake are produced not merely by a reduction or increase in pressure, but by differences in pressure (in fact all the air may be exhausted without applying the brakes unless the proper difference of air is created) the parts always moving toward the lower pressure when the difference is great enough to overcome the resistence of friction, etc., and remaining stationary when the pressures again become equal.

The operation of the air brake is due to that property possessed by air of always tending toward a state of equilibrium with the atmosphere or equality of pressure throughout any self-contained closed system. Thus, in the brake system, if, when pressures are equal, this relation is destroyed, the moveable parts upon which the pressures act will move in the direction of the lower pressure, and this movement may alternate in either direction according as the pressure is highest first on one side and then on the other of the dividing movable part. This is illustrated by the movement of the triple piston, which, when operating, first moves toward the lowering brake pipe pressure, then when the brake pipe pressure becomes stationary and the reservoir pressure becomes

lower, because air is flowing from it to the brake cylinder, the direction of movement of the triple piston is reversed, and the triple piston moves toward the now lower auxiliary reservoir pressure, and, as this movement cuts off the flow of air from the auxiliary reservoir, a state of approximate equilibrium now exists and the parts become stationary and will remain so until the relation of pressures is again changed.

If these principles which govern the brake are understood, any problem involving the operation of the brake may be readily solved and this applies not only to one type of equipment, but to all types of automatic brakes. Here we see the difference between learning to trace the air through ports and passages and understanding the principles of operation, for if the brake applies, the pressure of the brake pipe must have fallen below that of the reservoir; if the brake releases, the pressure in the brake pipe must be higher than that in the reservoir; if the brake does not apply or release, when apparently it ought, most certainly the difference of pressure essential to its operation is not being obtained and as the law in the case is positive and invariable, there can be no deviation from what is herein set forth. A realization of this will produce the state of mind necessary to approach a problem in connection with any particular device, for knowing what parts are subject to pressure, during the operation being considered, it becomes a comparatively easy problem to trace back from effect, which is necessarily in evidence, to cause, and, therefore, reach an intelligent conclusion as to whether the operation is normal or abnormal, or whether produced by defect or disease.

It is plainly pertinent here to mention that when considering the operation of the air brake, it must be considered as a whole, and not the different valves separately, for each part is influenced by some other part and the brake operates as one equipment, combining everything in the system from the air inlet of the compressor to the angle cocks on each end of the train, therefore, any evidence of irregular operations in any particular part may be the effect, not of the defect or disease of that part but of some other in the system. For example, a brake may apply without any intentional brake pipe reduction having been made, this should not be taken as conclusive that there is anything wrong with the triple valve on this particular car, for it may be due to the pressure in the brake pipe not being maintained constant by the feed valve against leakage; in other words, the triple valve may be more sensitive than the feed valve which is contrary to natural conditions.

Again, the wheels may be slid under a car that has been running for a long time with no trouble of this kind; do not conclude that this car has too much braking power, for the trouble is probably due to the fact that the other cars in the train at this time are not braking as high as they should—thus the tendency of the properly braked car to stop more quickly than those under-braked permits them to pull or push it forward and thus causing the wheels to "pickup." These examples illustrate why it is so necessary to consider all the brakes in the train as one.

While the expression "flow" is often used in connection with the movement of air, it should be understood to mean expansion, for air differs from a liquid to which the term "flow" is generally applied, in

that it is compressible and, therefore, when under pressure will expand in any direction in which there is an opening, and yet the vessel from which it expands or flows will still be full of air, while if a vessel is full of water and some of it is allowed to flow out, the vessel is no longer full of water for it has practically no expansive property. It is the tendency of the air to expand that produces at one and the same time the movement of the parts of the brake system and the change of pressure, though it does not follow because the pressure has been lowered that the air is less in amount, for it may be due to an increase in volume; in other words it is not pressure that passes from the different receptacles of an air brake system, but air, and the increase of pressure in the receptacle to which the air passes is due to the increase in the amount of air therein, and will be great or small according to whether the volume of the chamber into which the air passes is small or large as compared with the chamber from which it expands. That is, it is the ratio of the two volumes that determines the increase of pressure in the one for any given decrease in the other; thus, if the piston travel is long, the brake cylinder volume is greater than when the piston travel is short and therefore for a given decrease in the auxiliary reservoir pressure the brake cylinder will not increase to what it will if the piston travel is short, yet the same amount of air passes to the brake cylinder in each case.

The air in an air brake system only becomes less in amount when some of it escapes to the atmosphere; thus, the decrease of the auxiliary reservoir pressure during a brake application is brought about by enlarging its volume by adding to it the volume of the brake cylinder, temporarily when making a partial application, permanently during a full application. When the air has done the work required of it in the brake cylinder, it is permitted to escape to the atmosphere and its place in the system must be supplied by air from the compressor.

No work is performed by the air in retarding or controlling the train until it reaches the brake cylinder, when it forces the piston out. To this piston, the levers, brake beams and brake shoes are so connected that the shoes are forced against the wheels creating friction between the wheel and the shoes, antagonistic to the adhesion of the wheel to the rail, thus dissipating the energy of the train and reducing its speed, or, as in grade work, preventing the accumulation of energy by not permitting the train to accelerate. The levers are not only used to transform the fluid pressure in the brake cylinder into a mechanical force, but to multiply it and this multiplication varies between predetermined limits, it being necessary because of this multiplication to provide for proper shoe clearance by fixing a standard brake piston stroke in the design.

From what has been said, it will be seen that there are four elements involved in every brake operation, namely: 1st, time; 2nd, amount of reduction or change of pressure in the brake pipe; 3rd, amount of cylinder pressure obtained; and, 4th, percentage of braking power. Only one of these is fixed, viz., the percentage of braking power. That is, a given pressure in the cylinder gives a certain braking power; all the rest is variable. For instance, the time required to reduce the brake pipe pressure a certain amount is varied by increasing or decreasing the length of the train because this changes the volume of air in the brake pipe.

The amount of reduction required to obtain a given cylinder pressure is varied by the ratio of the reservoir to the brake cylinder and the cylinder pressure obtained from a given decrease in reservoir pressure is varied by the ratio of the brake cylinder to the resrvoir, which ratio is varied by an increase or decrease of piston travel, as this in effect increases or decreases the size of the brake cylinder.

Plainly, then, all these elements must be kept in mind when considering any problem involving train control and it is only by knowing the relationship existing between the different elements that the cause of the results obtained can be deduced.

Not only does the foregoing enable us to understand the air brake, its operation, the causes of any irregular operation, and the necessity of proper operating conditions, but it proves that any system founded on these principles must operate. There remain, however, the questions of intelligent application of these principles, durability, simplicity and capacity to meet all conditions. and it is in these that the equipment considered in this book is supreme. Still no mechanical apparatus is so good as to be perfect and it is therefore a foregone conclusion that many irregular operations of this equipment will occur, brought about by neglect, wear and tear, and lack of understanding on the part of those concerned in its care and operation. What will cause irregular operation of this equipment will do the same with the other equipments; in fact, conditions that will make the old brake system very inefficient, and, in some cases valueless, will have little or no effect on this. Therefore if anything goes wrong (?) with this equipment, do not assume off-hand that the equipment is at fault, for it is probably reflecting improper operation or showing up the effect of "man failure" somewhere. Besides, blaming the wrong thing will never supply the remedy, while, if the true cause be found, it can be removed.

In conclusion, I would like to impress upon all the importance of the air brake, for it is at once the greatest safety device ever known, the most profitable investment the railroads have, tremendously increasing the earning capacity, and is the best friend the engineer and trainmen have ever had, consequently, it behooves all to be vitally interested in obtaining the proper knowledge of it, to learn how it should be manipulated and what is most important of all, that it should be properly cared for and maintained.

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Development in Air Brakes for Railroads

With a Brief Review of Past and Present Operating Conditions

BY

W. V. TURNER

AND

S. W. DUDLEY

Being a Paper presented before the New York Railroad Club—April Sixteenth, 1909

THE WESTINGHOUSE AIR BRAKE COMPANY
PITTSBURGH, PENNSYLVANIA

PREFACE

It is not only of interest to the individual, but important to the real progress of any art, to have, in concrete, permanent form a record of the fundamental principles established and determining factors involved in the development of improved apparatus or methods, as well as to what extent the theoretical advantages of such improvements have been realized under the conditions of actual service.

The paper which follows presents such a record. Broadly speaking, it covers the developments in the art of train braking, as applied to locomotive, passenger and freight service, during the past five or six years —a period characterized by a constantly increasing activity in all branches of transportation.

In reprinting this paper, opportunity has been taken by the authors to make slight revisions which lack of time prevented completing in time for insertion in the printed *Proceedings* of the New York Railroad Club.

THE WESTINGHOUSE AIR BRAKE COMPANY,
Pittsburgh, Pa.

November, 1909.

DEVELOPMENT IN AIR BRAKES FOR RAILROADS WITH A BRIEF REVIEW OF PAST AND PRESENT OPERATING CONDITIONS*

By W. V. Turner and S. W. Dudley.

The Importance of the Problem.

In commencing this subject, we should like to state that the art of braking, or the application of brakes for the purpose of controlling trains, has received very little consideration outside of George Westinghouse himself and a comparatively few scientific men throughout the world, and is therefore generally looked upon as the mere building of a piece of mechanical apparatus which can be applied in any haphazard fashion to the vehicle which it is intended to control. This, however, instead of indicating that the subject is a simple one, should be taken as evidence that the problems to be solved are exceedingly great, and we may say that there are comparatively few men in the world who comprehend what is involved. While we are going to attempt to-night to point out some of the problems and how they have been worked out, it is only as humble students of the great science which George Westinghouse so successfully developed to a practical operation,—of an art in which no man has yet carried progress and improvement to the degree which would have been possible had he remained in active connection with the work. However, times were not ripe and other fields needed his genius and the air brake was left for many years to meet new problems and conditions as they presented themselves with the apparatus practically as he left it. We know of no other mechanical device which has successfully met so many changes in conditions spread over such a long period, as the air brake.

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*NOTE—Preceding the reading of this paper before the New York Railroad Club, the following remarks were made by Mr. Turner:

There may be some who think an explanation is needed as to why such a long paper should be prepared for this evening. I can only say that it was our desire, as well as that of some other members, that a record of the development of the air brake be presented to this Club in such a comprehensive and complete form as to be useful as a reference in the future; this record to contain also a statement of the principles underlying the art of train braking, with sufficient illustrations taken from actual service to demonstrate the soundness of these principles and the effect of the improvements made.

To accomplish this object with a subject of such magnitude and complexity required a voluminous paper, but I assure you that notwithstanding its length every effort was made to keep it from being so CONCISE as to be OBSCURE.

As the paper is too long to read at one meeting, particularly if time is to be allowed for some discussion, I intend to read as rapidly as possible those parts which are intended chiefly to refresh your memories, omit reading those parts which are more or less technical, as also the consideration of locomotive and freight brakes in so far as they diverge from the general proposition and read more carefully those parts which cover the brake for passenger cars.

As this cannot be done in a few words, I must crave your indulgence if the reading takes longer than is usual for your papers.

Considering the subject of train braking as an art capable of being reduced to a more or less exact science, it is found at once to be a big proposition—quite too broad to be comprehensively treated in a single paper of this kind. It will therefore be necessary to omit much which would be of interest in connection with the evolution of the air brake as a factor in the material progress of the world, but it may be said that the air brake ranks next to Christianity, the press and the locomotive among those forces to which the material developments of the present age are primarily due. We know that most of you will look upon this as a sweeping statement, but the intercourse between peoples depends absolutely upon the ability to control the medium of interchange.

Starting and Stopping.

The problems of deceleration, retardation and the flexible control of trains must receive more and more attention from a scientific and technical standpoint, in order that today theory and practice may be combined to produce the best results in the shortest time. This is necessary if the brake is to efficiently and satisfactorily meet the wonderfully changed conditions which have developed since the invention of the quick action, automatic brake. The high speeds and great weights of the present day require that advantage be taken of every opportunity offered to increase and flexibly control braking power.

Starting and stopping of trains are complimentary factors in the problem of making time between stations, therefore it is evident that the best results can only be obtained where both factors are given due consideration. Generally, the starting factor is the only one fully considered, or, at least, the one more fully provided for, and this notwithstanding that better results can be obtained if both are considered and the more efficient brake system installed.

In another sense, the question of stopping is the most important, as the safety of the service and the freedom from delays to a great degree depend upon it. The measure of the value of the brake is twofold—1st, the ability to stop in the shortest possible distance when necessary; and 2nd, to permit short, smooth and accurate stops being made in regular operation, therefore both these factors should be considered when design is underway.

Unfortunately, the brake is usually looked upon as a safety device only, and we believe it is because of the prevalence of this idea that its installation and maintenance do not receive the consideration it merits. Considering the investment, there is no part of the railway equipment that will give greater material returns than the brake when properly installed, operated and maintained. If the brake could to some extent be separated from the idea or impression that it is a safety device only and proof advanced to show that it permits of the hauling of heavier cars; in fact, makes the heavy car possible—that it makes possible faster and more frequent service—as much or more than does the locomotive, the block signal and the good road bed, and that, if given the consideration it should have, it would increase the possibilities, profits and value

of all these things—then, we believe, its importance would be more fully appreciated and, therefore, at least the same consideration be given to its design and installation that is accorded to other parts of railway equipment. A safety device, the brake is, par excellence; but it has other reasons for its existence.

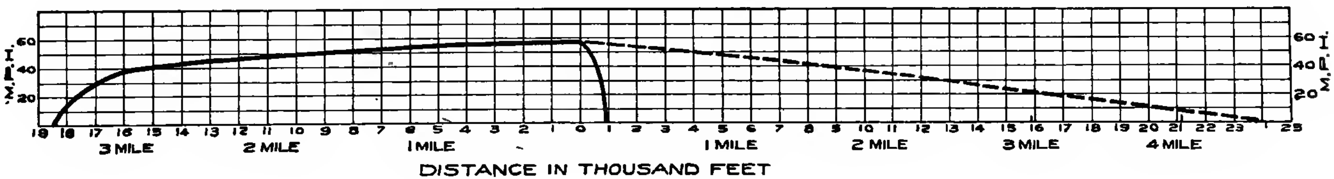
Very few, perhaps, realize that the brake under a single car is much more powerful than the locomotive that pulls the train, yet this will be apparent to any who examines the records of a dynamometer car alone attached to an engine, the stops being made by brakes on the dynamometer car. Few realize that it takes a locomotive perhaps five minutes, perhaps ten minutes, and a distance of some miles—six or seven—to attain a speed of sixty miles per hour. Imagine the state of affairs if it took a brake that length of time and distance to stop the train. The comparison is somewhat startling, but it is only because the condition is one of those commonplaces which have been taken for granted so long that they are accepted as inherent rather than being given the degree of consideration which their significance warrants. Fig. 1 is an illustration of the facts stated, taken from the records of a run during a series of tests at Absecon, N. J., 1907, the train being composed of a locomotive and ten cars. What it took the locomotive nearly six minutes and a distance of about three and a half miles to accomplish was overcome by the brakes in less than twenty seconds and within a distance of about one thousand feet. The broken line represents what the stop might have been if no brakes had been used, *i. e.*, the train brought to rest by the resistance of the air, and journal friction—all of the elements so strongly contrasted in Fig. 1 are familiar in themselves but their reciprocal relationship is often overlooked. We are able to stop the average passenger train of today from a speed of sixty miles per hour in about twenty seconds time. To build a steam locomotive that would accelerate a train in the time and distance that the brake stops it, would be impossible, for in order to have the adhesion to the rails, which would permit of developing the required draw bar pull, the steam locomotive would have to weigh approximately twice as much as the train itself, which is, of course, prohibitive. Electric locomotives, however, are no longer to be regarded with uncertainty or as mere experiments and we have every reason to believe that the electric locomotive will be able to accelerate a train to a speed of sixty miles an hour in certainly not more than a minute and a half, and probably not more than one minute's time. That means that the brake is going to be even *more* important in the future than it has been in the past. In proportion as we accelerate, we must perforce be prepared to decelerate. The ability to accelerate, or even to run at high speeds, must be measured by the ability to stop.

As an example, however, of how little this is appreciated, we are often called upon to answer such a question as this, "In what distance should a train be stopped from a speed of fifty miles per hour"? Perfectly simple, isn't it? Here we have one known factor, from which we are expected, apparently, to derive all the other factors which are of equal importance and must be known before an answer of any value can be given to such a

CLASS E-2-D LOCOMOTIVE.

TOTAL WEIGHT OF TRAIN	559.6 TONS.
ACCELERATION	DISTANCE OF 18500 FEET
TIME OF ACCELERATION	5 MIN. 47 SEC.
DECELERATION	DISTANCE OF 954 FEET.
TIME OF DECELERATION	18.7 SEC.

TOTAL ENERGY STORED IN TRAIN AND OVERCOME BY BRAKE 63250 FOOT TONS



BROKEN LINE REPRESENTS STOP WITHOUT THE USE OF BRAKES.

NOTE:- THE CALCULATED STOP WITHOUT BRAKES WAS OBTAINED BY ASSUMING 9.6 POUNDS PER TON RETARDATION DUE TO WIND RESISTANCE AND JOURNAL FRICTION. TRACK LEVEL.

W. A. B. CO'S. EMERGENCY HIGH SPEED BRAKE TESTS.

ABSECON, N. J. W. J. & S. R. R. MARCH, 1907

CURVE OF ACCELERATION AND DECELERATION

TRAIN OF ONE ENGINE AND TEN CARS. TEST No. 54.

question. A few of these factors are: the light weights and loads of the vehicles composing the train; the percentage of braking power used with engine and cars; whether or not all wheels, including truck and trailer (if any), of the locomotive were braked; amount of coal and water on tender; what type of brake equipment was used; what pressures were carried; whether the train was accelerating or decelerating; on a curved or straight track; on an ascending or descending grade, or level; the condition of the rail; whether the brakes were applied in service or emergency, or ordinary service and then emergency; the piston travel on each vehicle; the losses due to friction of parts, brake beam release springs, etc.; wind resistance; quality and thickness of brake shoes and method of hanging them, for this affects materially the efficiency of the brake, both as to absorbing power and lengthening the piston travel which reduces the pressure otherwise obtainable. Furthermore, we do not intend to say that the precise effect of each of these could be accurately calculated, even though full information were at hand, and little thought will make it evident that each of the factors mentioned above may have a considerable influence on the length of the stop.

We merely mention these things to show you the great importance of the air brake and the necessity for considering carefully what principles govern its action. It does not make very much noise. You do not hear as much about it in the papers as you do about electricity, for instance; yet it has been much more of a factor in railroad development up to the present time than electricity.

The Application of the Problem.

The application of a straight air brake is, comparatively, a very simple proposition, although it has had to meet many varied conditions. But with the application of automatic brakes the problem becomes altogether different; many very valuable features possessed by the straight air brake had to be sacrificed to obtain the one prime factor in the braking of cars that is certainly nearest the heart of every manager of railway property in this country, that is, *safety*.

We may say here that with the automatic brake on connected cars a pipe runs through the train which is charged with air and is in communication with a triple valve under the car and that, in turn, with an auxiliary storage reservoir which is charged with compressed air for the braking of the vehicle on which it is carried, which in its turn is connected to the brake cylinder whenever the brake is applied. Consequently, if anything ruptures the pipe, thereby permitting the air to escape from the brake pipe side, but not from the auxiliary reservoir side, of the piston of the triple valve, the higher auxiliary reservoir pressure then acts upon the piston of the triple valve, moves it toward the lower pressure, carrying with it the slide valve, which, in turn, registers ports communicating with the brake cylinder, and the compressed air in the auxiliary reservoir then flows to the brake cylinder and applies the brake. That is all there is to the automatic brake so far as its automatic feature is concerned.

When, however, the action of the brake on a rapidly moving train is carefully analyzed the factors affecting the final result are found to be most varied and complex in character. If the question were asked: "What stops a train"? no doubt most of you would say that it is the frictional force between the shoes and the wheels. That is the primary cause, but you can easily see that there must be some other factor in the case, because, if the rails were made of ice, for instance, it is obvious that the application of the brake shoes to the wheels would not stop the train within a very long distance; it would simply lock the wheels so that they would slide, but only gradually overcome the momentum of the train. Again, if it were possible, when moving at a speed of, say, sixty miles per hour to lift the train from the tracks and then apply the brakes, you can readily see that the application would not stop the train. There must, therefore, be some other factor besides the friction of the shoes on the wheels, and that factor is the "adhesion" between the wheels and rail. Therefore, the highest possible retarding frictional force that can be obtained with a brake is such as would almost equal the adhesion of the wheels to the rail. If it is increased beyond this point, the wheels will slide, and, as you know, sliding friction is far less effective as a retarding force than rolling (static) friction, consequently, the stop would not be made in as short a distance as when the wheels are kept revolving, but being retarded by the friction between wheel and shoe. We have endeavored to produce with our brakes a means for obtaining the highest average braking power possible that will not slide the wheels under average conditions. That is all that can be done as far as brakes are concerned. You have heard, no doubt, of brake schemes whereby the apparatus would lock the wheels immediately in an emergency, and the train was thereby to be stopped in a shorter distance than by any other brake in existence. This is absurd, even if we neglect the flattening of the wheels that would result by such operation. The wheels must revolve, and in order to stop in the shortest possible distance the maximum braking power that will still permit this is required.

Not only must the brake dissipate energy due to momentum when bringing a train to a stop but it must prevent the accumulation of energy, and this, at times, is its chief duty, as, for instance when descending a grade. A train of 3,000 tons commencing the descent of a two per cent. grade at a speed of ten miles per hour, would in three minutes, due to the acceleration of gravity alone, be moving at a speed of over 70 miles per hour, due allowance being made for air and internal resistances, and the kinetic or "wrecking" energy stored up in the train would be 490,000 foot tons, sufficient to raise the train to a height of 160 feet. Thus you see that the brakes must dissipate in three minutes 490,000 foot tons if the speed at the end of this time is not to be higher than at the beginning.

But the braking power at hand must be available not only for one application but for any number of them. With the automatic brake, the ability to recharge the auxiliary reservoirs has fixed the limit to the number of full applications obtainable. Therefore, in order to obtain the maximum possible safety with an automatic brake, two things are

necessary, first, the highest possible braking power; and second, means of obtaining that power at any time, no matter how thoughtless or foolish the operator may be in wasting the air.

What has been said cannot fail to impress all of us with the importance of this problem of railroad operation, not only as affecting the safety of the passengers, the preservation of the freight, the protection of the rolling stock, but as also affecting economy of operation with respect to time and the earning power of both men and equipment, which is the important factor in determining whether the investment is profitable or otherwise. Obviously, the more congested the traffic the greater the loss in all these things if the brake, its maintenance and operation, is not what it should be. It is true that the returns of the brake are largely indirect, as are those of the road-bed or from the coal that goes through the fire box, but they are none the less sure and of greater per cent. On the other hand, if neglected, the effect is much the same as indirect taxes, by means of which, as you know, one may be taxed into bankruptcy without knowing it.

The Requirements of a Brake.

Where so much gain or loss depends upon the control of trains, it must, therefore, be remembered that although stopping power is the first, it is not the only consideration. In order to most efficiently meet the demands of modern service conditions and provide for those of the immediate future, the brake must combine flexibility and simplicity with safety, besides being perfectly interchangeable with existing apparatus and as far as human foresight and ingenuity can make it, fool-proof. A brief consideration of these requirements of a perfect brake will make manifest their fundamental bearing on the problem.

A practically perfect brake must be automatic, durable, simple, always ready, responsive and flexible, the latter of which involves the elements of power, time and amount of reduction, and in addition it is imperative that in case of an emergency the maximum braking power contemplated in the design be obtained with the time and reduction elements reduced to a minimum, to the end that the stop be made in the shortest time possible. For service or regular operation, however, all these elements should be extended, to the end that trains can be handled without shock and accurate stops made, and these factors vary in importance and degree according to the service. Where the speed is generally high, the power element should have chief consideration, while where the speeds are generally low, the other elements should have predominance in the design. It is where the speed varies from very high to very low (and this is often the case) that all elements must have equal consideration and each be developed along lines that will mean the least sacrifice to the others, keeping in mind at all times that, in the event of danger, to stop is the chief consideration. These requirements are only fulfilled in the air brake, therefore, this will be the one considered. In order that the necessity for the progressive development of the air brake may be in mind, a brief review of operating conditions is pertinent.

In making ordinary service stops in passenger service there are always three things to be considered: accuracy, smoothness and the question of time. The shortest possible stop that can be made, is to fully apply the brake and allow the train to come to a standstill, but in so doing, two things are sacrificed—accuracy and smoothness. It certainly would not be a smooth stop, and the accuracy would depend entirely upon the judgment of the operator when making that particular brake application. The smoothest possible stop is to shut off and drift to a standstill. In this case, a great amount of time is sacrificed, and the point where the stop would be completed would be altogether indefinite. As a result neither of these methods can be used in practical operation.

To obtain all three points mentioned, we must have means of applying the brake with the maximum cylinder pressure that the speed will warrant and when approaching the place at which the stop is to be made by this means, to feel our way to the proper point of stop and have comparatively little pressure left in the cylinder when the stop is completed. Thus we make the shortest stop, smoothness and accuracy considered, that is possible. Then, having very little, if any, pressure in the cylinder to get rid of, when the signal to start is given, the start may be made immediately. The brake which possesses all these features is certainly a flexible one. The brake which originally possessed them to a maximum degree was the straight air brake. But this perfection is now also possessed to the same degree by the new passenger brake equipments to be described, and has been secured through means which insure a higher degree of safety than ever obtained before in the art of braking.

Coming now to the point of simplicity, the straight air brake also possessed this feature to a marked degree so far as operation is concerned. The same degree of simplicity will, perhaps, never be obtained in a purely, automatic system because, as you are aware, certain complications arise in the operation of an automatic brake which are not present with straight air as, for instance, when a number of cars are coupled together. While it is, of course, desirable to keep the apparatus used as simple as possible, the fact that we have complications is not necessarily detrimental and it does not follow that a more complex system should not be adopted. We would not consider going back to the old wood-burning locomotive in place of the splendid, but vastly more complex, locomotives of today, simply because the latter are much more complicated. It is a question of results. If the results obtained justify the means employed, that is sufficient.

We feel that in the recent development of automatic brakes, especially those for passenger service, we have, all things considered, increased the simplicity, greatly over that of the old standard. With the latter, proper operation depended largely upon the kind of man who handled it—his experience, knowledge of the brake, judgment and intuition; being unable to graduate his release, he required a far greater perception of distance and speed and better judgment in making the stop,

also knowledge of the road, condition of the rail, and other factors that necessarily enter into automatic brake operation. These affected the operation of the old brake in a much greater degree than the new.

Another feature of distinct advantage from an operating standpoint is that of "fool-proofness." By this we mean those characteristics of the design whereby the human element is reduced to the lowest possible factor. With the old standard type of passenger equipment, it was possible to so use the air supply as to seriously reduce the available braking power in a comparatively short time. With the new equipments, this possibility is made vastly more remote, as maximum braking power is at all times available. Also, the auxiliary reservoirs being recharged as fast as the brake cylinder pressure releases there is always the same stored pressure to draw from. Moreover, the brake will always respond and for a given reduction the same cylinder pressure will result. As a consequence, the engineer, knowing just what results he is to obtain, will have more confidence in the brake and his own ability, and the results will be apparent both in the schedule and power consumed.

The problems of installation, operation and manipulation, however, are infinite and the human equation is perhaps more of a factor than in any other mechanical science. Yet, I venture to say, that many railroad officials give more consideration to the color of the paint used on the rolling stock than to the problems enumerated above; paint is looked upon as attractive, the brake often as a necessary evil, all of which proves that a man cannot *know* anything about that of which he has no conception, for, aside from any consideration of the safety feature, there are probably few investments that a railroad manager can make that will return as large a dividend as a good brake, properly installed and operated.

Fundamental Principles in Brake Design.

In the establishment of a logical basis of brake design, applicable to the conditions under which brakes in general must operate and involving a determination of the essential factors of an elementary brake system for any given car, we find that the starting point must be the light weight of the car. Fortunately, as we shall see later, this can usually be determined in advance to any desired degree of accuracy. In order to fix our ideas, suppose for an instant that the car was fully equipped with a complete brake equipment and by an analysis of the factors involved in stopping the car, determine how these factors may best be provided for in the design.

Assuming that the wheels do not skid, the actual *braking force* acting on a car when the brakes are applied is the force of the friction between the brake shoes and the wheels, tending to retard the rotation of the wheels and thus stop the car. The relation which this bears to the energy stored up in the moving car, provided the "adhesion" of the wheel to the rail is not exceeded, determines the effectiveness of the brake and the length and time of stop. The energy of the moving car

consists of two parts—that of the car as a whole due to the velocity of translation and that of the revolving wheels, due to their rotation, and varies as the weight of the car and as the square of its velocity.

The latter may be taken at about 5% of the energy of translation for 12 wheel cars and about 2% of the energy of translation for 8 wheel cars. In ordinary calculations, however, this factor is usually neglected, and properly so, because for modern rolling stock the resistances other than as derived from the brakes, such as internal friction, air resistances, flange friction and so on, has been shown by actual experiment to at least equal if not exceed the inertia effect of the revolving parts. Consequently a greater error is made by considering the energy of rotation *without* at the same time taking into account the resistances to motion which exist due to other causes than the brake shoes (which, it should be noted, are usually indeterminate and subject to considerable variation) than to assume that these two opposing factors neutralize each other.

The frictional force between the brake shoes and wheels depends on the pressure acting on the shoes and the coefficient of friction between the shoes and the wheels. In making a stop, therefore, the factors involved, so far as retarding the rotation of the wheels is concerned, are:

1st—The brake shoe pressure commonly called the "braking power."

2nd—Coefficient of friction between the shoes and the wheels, by which the brake shoe pressure must be multiplied in order to determine the actual retarding force.

3rd—The weight resting on the wheels.

4th—The velocity of the car.

5th—The rotative energy of the wheels, it being assumed throughout that the wheels do not skid.

The only one of these factors which we can even partially control in service, or fix arbitrarily in designing the brake system, is the pressure on the brake shoes. Inasmuch as the wheels must not skid when the weight resting on the wheels is least—that is, when the car is not loaded—the light weight of the car must be taken as the basis of calculation regarding brake shoe pressure, except in the case of some form of "empty and load" brake. Since the "braking power" is by custom, measured by a scale of percentages wherein 100 per cent. represents a shoe pressure on each wheel equal to the pressure of that wheel on the rail, the problem is then to determine and insure the obtaining of the proper relation between the brake shoe pressure and the light weight of the car.

As pointed out above, the factors involved such as frictional coefficients, speed, weights, etc., are so subject to variation in service that *no theoretical* conditions can determine the proper nominal percentage braking power (*i. e.*, the ratio of brake shoe pressure to light weight of car), which shall best meet average road conditions. This can be fixed only by experiment and experience and is *subject to modifications as conditions change* or become more thoroughly understood. For example, many years' experience has proven that 90 per cent. braking power for

passenger cars gives satisfactory braking effects with a reasonable margin against wheel sliding and sufficient power for service stops. This was determined by the results obtained on the *lightest* cars. So far as wheel sliding is concerned, a 150,000 lb. car braked at 95½ per cent. has practically the same margin against wheel sliding as a 70,000 lb. car braked at 90 per cent. But if the percentage of braking power is varied, the uniformity of braking effect, other factors being the same, is lost. *Therefore, the percentage of braking power determined as a satisfactory maximum for the lightest* cars is adhered to on all cars, in order to bring about as nearly as possible the uniform results which are necessary for satisfactory service operation.

Having, therefore, chosen a certain percentage of braking power which should be obtained on all cars, it is evident that what actually is obtained, in any given instance, depends on the total leverage ratio and the pressure per square inch on the brake piston. It will be apparent that all resistances between the brake piston and brake shoes, such as release springs, reactions of hanger links, friction of rigging, etc., must necessarily be ignored until the essential factors in the design are determined upon.

The total leverage ratio is fixed within certain limits by purely mechanical considerations, with regard to piston travel, shoe clearance, etc., and, once the foundation brake rigging is designed, remains always the same.

Hence in any given case the percentage of braking power actually obtained depends entirely on the pressure existing in the brake cylinder, which varies in practice from zero to the maximum obtained when an emergency application is made.

In designing the brake system for a car, therefore, the leverage ratio and size of brake cylinder must be so proportioned as to give the required braking power in pounds, *with some arbitrarily chosen pressure in the brake cylinder.* Evidently this braking power will be obtained in practice when the brake cylinder pressure is that on which the design of the brake system was based. For any pressure lower or higher than this, the braking power, in pounds, will be correspondingly lower or higher than the nominal. Furthermore, the actual percentage of braking power (ratio of brake shoe pressure to weight on wheels) varies not only with the brake cylinder pressure but also with the condition of the car—whether loaded or empty.

From a consideration of these conditions it would seem practically impossible to insure absolute uniformity of brake action on different cars in service by any method of design. The best that can be done is to establish and adhere strictly to the assumed standards upon which such designs are based. These are:

1st—The "percentage of braking power" in terms of the light weight of the car.

2nd—The brake cylinder pressure upon which this percentage is based.

The former, as has already been stated, must be determined from experiment and experience. The latter must be chosen arbitrarily, but it

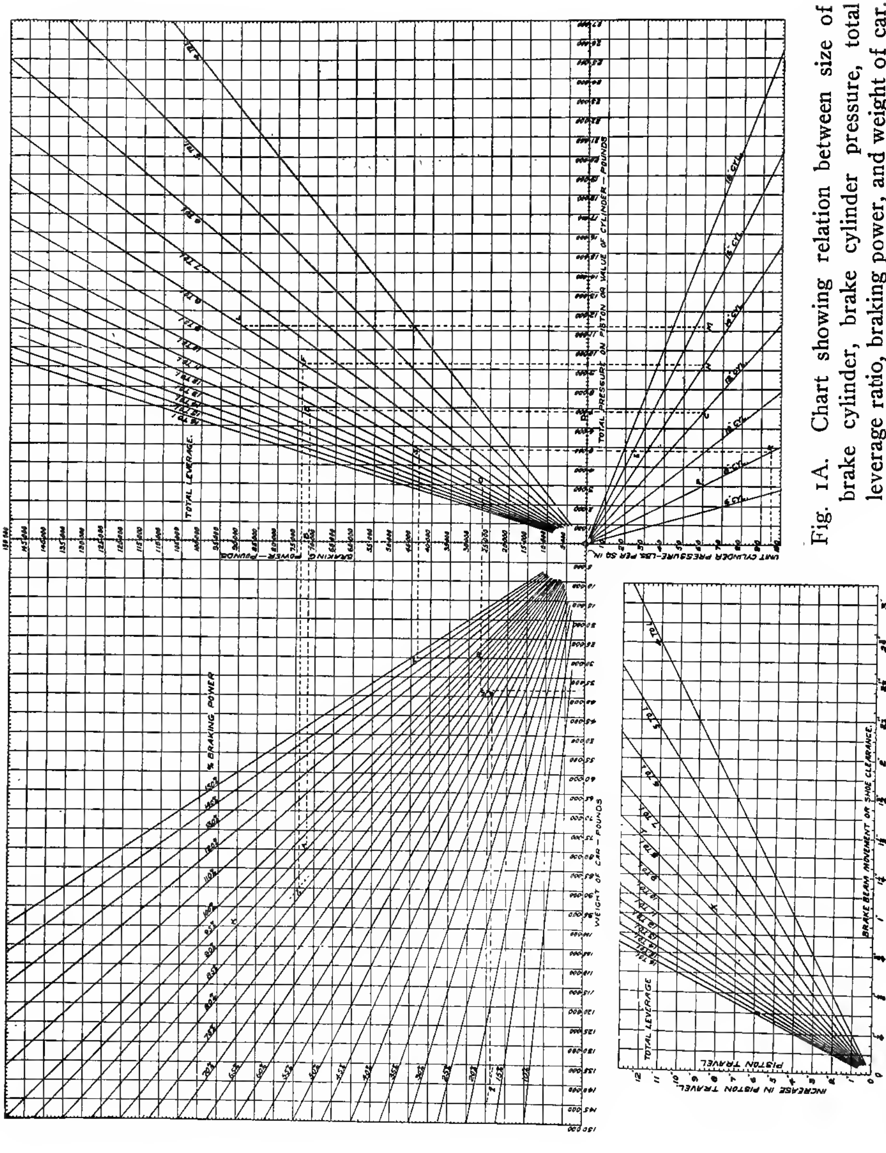


Fig. 1 A. Chart showing relation between size of brake cylinder, brake cylinder pressure, total leverage ratio, braking power, and weight of car.

should have the same value for all brake calculations, in order to insure a common base being universally used and understood. Fig 1A graphically illustrates the relations existing between these two factors for different weights of cars and total leverage ratios. The question now is, therefore, "What brake cylinder pressure should be used as a basis in designing the brake systems of all types and classes of cars?"

With a given auxiliary reservoir charged to a standard pressure, and with a given brake cylinder having standard piston travel, a certain definite pressure of equalization is obtained, which is constant so long as the other factors involved are kept constant.

When an emergency application is made, since a portion of the air in the brake pipe or other source of supply is used in addition to that in the auxiliary reservoir, the brake cylinder pressure is augmented in proportion, and a higher maximum pressure therefore obtained. Evidently its value must depend upon the relation which the supplementary volume bears to that of the auxiliary reservoir and brake cylinder combined. With equipments now in general use this ratio must necessarily decrease as the size of the car increases because the brake pipe volume remains practically constant for all sizes of cars, while the brake cylinder and auxiliary reservoir volumes increase as the size of the car increases. It then follows that where air from the brake pipe alone is used to augment the brake cylinder pressure in emergency applications, the emergency pressure thus obtained must vary with the different combinations of auxiliary reservoir and brake cylinder necessary for different sizes of cars—the gain in pressure from this source over that obtained in full service equalization being greatest with the smallest sizes of auxiliary reservoirs and brake cylinders.

Hence in choosing a brake cylinder pressure on which to base brake calculations, that obtained in emergency, which was satisfactory where the brake cylinders were of such size that a uniform pressure was obtained in both service and emergency, is now excluded at the outset—from the standpoint of uniformity—since in the nature of the case it is not uniform for all weights of cars. This is for the reason that we now have brake cylinders varying from 6 in. to 18 in. diameter with widely varying pressures in emergency. And if the braking power desired is based on a brake cylinder pressure higher than can actually be obtained, then for lower cylinder pressures the brake is not so effective as it might be made, were the braking power based on the pressure actually obtained. The smaller cars which do obtain this pressure, give the calculated braking power in emergency, but the heavier cars cannot, and there is a loss, both in uniformity of emergency action and possible efficiency.

On the other hand, for brake pipe reductions less than sufficient to produce equalization, the cylinder pressures obtained are uniform, provided the other factors are uniform in value and the pressure at which the auxiliary reservoir and brake cylinder equalize is supposed to be the same for all combinations of reservoirs and cylinders, with the same initial pressure. To obtain this uniformity it is only necessary to properly

proportion the reservoir volume to the brake cylinder volume for some standard piston travel. We then have a pressure base which will be constant when the other factors involved have their proper or standard values. It would then seem that this is the basis to which all braking power calculations should be referred, for the reason that it is the nearest approach to a uniform and constant pressure obtainable under the wide range of conditions governing this choice. This adds to the standards enumerated on page 11, the following:

3rd.—This brake cylinder pressure must be the equalized pressure of the auxiliary reservoir and brake cylinder.

4th.—A predetermined ratio between auxiliary reservoir volume and brake cylinder volume to produce this equalization must be adhered to.

The fundamental steps in designing a brake system for any given car may now be outlined as follows:

Given the light weight of the car—from results of experiment and experience—the proper braking power, per cent. has been established and this enables the total brake shoe pressure to be calculated.

Mechanical considerations fix the total leverage ratio between certain limits, the maximum and minimum values of which enable a maximum and minimum total brake piston pressure to be calculated from the preceding.

This total brake piston pressure depends upon the size cylinder and pressure per square inch used as a basis. The pressure basis to be used should be that agreed upon as a universal standard, for such calculations as this, and, as has already been pointed out, uniformity requires that the *equalization pressure* (50 lbs. per square inch), from the lowest standard pressure carried, should be the base chosen.

Having determined the unit pressure, the size of cylinder can be chosen from the standard sizes manufactured to give the desired braking power with a total leverage within the maximum and minimum limits as defined above.

To obtain the desired 50 lbs. equalization pressure from the standard 70 lbs. brake pipe pressure with a standard piston travel, is simply a matter of correctly proportioning the auxiliary reservoir volume to that of the brake cylinder at the piston travel employed as standard.

We then have an auxiliary reservoir which, at 70 lbs. initial pressure, will equalize with its brake cylinder, when this has eight inches piston travel, at 50 lbs., and the brake cylinder piston is of such an area that the total pressure thus obtained, when multipled by the total leverage, will give a total brake shoe pressure equal to the desired percentage of the light weight of the car.

To be sure, in an emergency application, the braking power on all cars will be greater than that used in the design and the lighter the car the greater the variation between service and emergency braking powers. But such non-uniformity in actual service is bound to obtain, and always has, since an increase to 90 lbs. or 110 lbs. brake pipe pressure, or a variation in piston travel produces similar results, to say nothing of

losses due to leakage, resistances and variations in frictional coefficients. The advantage gained, however, by the method of design outlined is, therefore, in the fixing of a uniform and actually obtainable brake cylinder pressure, which is necessary for service operations and is one of the most important factors in the calculation to be made.

It may be said in passing that with the more recent types of brake equipments for passenger service, using a supplementary reservoir volume, in addition to that of a brake pipe to produce high emergency brake cylinder pressure, the size of supplementary reservoir used is calculated to give practically uniform brake cylinder pressures in emergency applications with *all* sizes of brake cylinders, thus taking advantage of high pressures for emergency stops and at the same time conforming to the principles of uniformity laid down above, it being a fundamental principle of modern brake design to keep the service equalization brake cylinder pressure comparatively low, for reasons fully explained elsewhere, and use as high an emergency equalization pressure (as large a supplementary reservoir), as may be desirable.

In the attempt to secure a high emergency brake cylinder pressure without the aid of the supplementary reservoirs referred to above, the relationship between brake cylinder and auxiliary reservoir volumes existing in the *original* brake design was gradually lost; the auxiliary reservoir volume being increased slightly, from time to time, as heavier cars, requiring larger brake cylinders, were equipped. On the lighter equipment the variations thus introduced were relatively unimportant, but in the case of heavy cars, requiring the 16 in. and 18 in. cylinder, it was impossible to increase the auxiliary reservoir volume sufficiently to obtain the desired emergency pressure, without at the same time interfering to a marked degree with the proper operation of the equipment in service. Consequently, a compromise was made, so as to obtain as high an emergency cylinder pressure as possible without increasing the service equalization pressure to an extent inconsistent with the proper normal functions of the brake.

By the aid of a supplementary reservoir volume, however, reserved during service operation, but available in emergency applications of the brake, it is now possible to obtain the required increase in stopping power for emergencies and at the same time return to the original volume relationships, the correctness of which had been established by long experience.

These relationships are determined by the following principles, which will be recognized at once as having been followed, perhaps more or less unconsciously, in even the earliest automatic brake designs:

1st.—For any given arrangement of leverage between the brake cylinder piston and the brake shoes, the "braking power" is directly proportionate to the gage pressure of air produced in the brake cylinder. (A)

2nd.—The limitation of the maximum allowable pressure of air in the brake pipe limits thereto the available pressure in the auxiliary reservoirs. (B)

3rd.—With this fixed maximum charge in the auxiliary reservoir, the highest pressure obtainable in the brake cylinder from this single source is that at which the air pressure equalizes between the two. This (absolute) pressure, therefore, equals the product of the initial absolute pressure in and the volume of the auxiliary reservoir divided by the sum of the volumes of the auxiliary reservoir and of the brake cylinder (neglecting all clearance volume, temperature effect, etc.), and the "braking power" is as the corresponding gage pressure. (C)

4th.—This pressure of equalization should be limited because its height determines the range of those differences between final auxiliary reservoir pressure and initial brake pipe pressure, which range affords the control of "braking power" applied. (D)

5th.—That while low pressure of equalization limits "full service" pressure, yet small range precludes nicety of control, especially as from the range there must be deducted such initial difference of pressures as are necessary to overcome the inertia and friction of the triple valve parts. (E)

6th.—That to afford heightened brake cylinder pressure for use in emergency another quantity of air is necessary, and if this be, as in all past practice, that contained in the brake pipe, the resulting absolute pressure will be equal, theoretically, to the maximum absolute brake pipe pressure multiplied by the volume of the auxiliary reservoir plus the amount of air, in cubic inch pounds, obtained from the brake pipe, this sum then divided by the volume of the auxiliary reservoir plus that of the brake cylinder, and the measure of the resulting braking pressure is the gage pressure corresponding to this resulting (absolute) pressure. (F)

Now, it is the interdependence and reactive results of these simple and recognized principles in their combinations, together with a corresponding proportioning of leverages between the brake cylinder piston and the brake shoes that determine the relative efficiency of a brake design.

From (F) it is seen that if other parts be enlarged the volume of the brake pipe, which is practically the same on all cars, becomes relatively small and the emergency pressure obtained is so insufficient that in the equipments for heavy rolling stock resort has been had to enlarged auxiliary reservoirs with a corresponding heightening of the "full service" pressure (C) and a resulting lessening of the range of control. (D)

Again when (C) is heightened while (D) is lowered, the results of the lighter brake pipe reductions cause magnified effects in the service braking, so that, when it is realized that such range as is possible is lessened by the lack of sensitiveness of the triple valve (E), the likelihood of roughness of service stops, becomes self evident.

Such being the case, it is apparent:

1st.—That there is a ratio of volume of auxiliary reservoir to that of brake cylinder that should not be exceeded.

2nd.—That such service pressures as result in the brake cylinder should be made sufficient by a corresponding proportioning of the leverage.

3rd.—That the volume of each car's part of the brake pipe should be supplemented by proper means so as to afford the required braking pressure in emergency.

Starting, therefore, with a brake cylinder of the size *dictated* by the vehicle to be equipped, as already explained, and by a proportioning of the leverage which shall accord with the service required, let us assume that

C = Volume of brake cylinder, in cubic inches.
P = Service equalization pressure, in absolute units.
R = Volume of auxiliary reservoir, in cubic inches.
a = Absolute initial pressure in the auxiliary reservoir.
r = Permissible range of brake pipe reductions.

We have first, from the above definitions, that

$$r = a - P$$

and from (C) above, neglecting clearance volumes:

$$\frac{a \times R}{R + C} = P$$

from which

$$R = \frac{P}{a - P} \times C$$

$$= \frac{P}{r} \times C$$

which may be expressed in the following law:

The proper auxiliary reservoir volume, according to the principles laid down above, is equal to the volume of the brake cylinder determined upon multiplied by the ratio of the service equalization pressure fixed upon as standard to the permissible range of brake pipe reductions.

Assuming, as is current practice, that P = 50 lbs. per sq. in. (gage) and a = 70 lbs. per sq. in. (gage), then we have

$$r = a - P = 20 \text{ lbs.}$$

and

$$R = \frac{P}{r} \times C$$

$$= \frac{65}{20} \times C$$

$$= 3\tfrac{1}{4} \times C$$

That is, the volume of the auxiliary reservoir should be 3¼ times the volume of the brake cylinder. It is plain, however, that the effect of the

clearance volumes, leakages, temperature and other adverse influence will be such that to obtain the desired results in actual service a somewhat higher auxiliary reservoir volume must be used than that found by the above calculations, for example, with the standard 8-inch equipment, an auxiliary reservoir volume of 1620 cubic inches is used, which is about 3½ times the brake cylinder volume.

In determining the proper size of supplementary reservoir to be used —(F above)—a similar reasoning may be used. In addition to the symbols already defined, let

S = Volume of supplementary reservoir in cubic inches.

E = Absolute emergency equalization pressure.

Assuming for the purposes of calculation that the emergency pressure is the result of the equalization of the brake cylinder, auxiliary reservoir and supplementary reservoir volumes, we have

$$\frac{a\,(R + S)}{R + S + C} = E$$

whence, by proper substitution and reduction, we derive

$$S = \frac{a\,(E - P)}{r\,(a - E)} \times C$$

While the above expression is interesting as showing the simple relation which exists between the various volumes involved in the typical equipment as we have assumed it, it must be clearly understood, 1st, that we have supposed all the additional air supply in emergency to come from the supplementary reservoir, having taken no account of that vented from the brake pipe; and 2nd, that in any actual installation similar to that we have discussed, the equalization is dependent upon the movement of certain valves actuated by spring and air pressures in combination, the resultant effect of which is such that in the actual working equipment the state of affairs is by no means as simple as has been assumed for the typical equipment. Instead of equalization taking place between all the volumes concerned simultaneously, there are time limitations imposed on the rate of flow from the various sources of air supply to the brake cylinder, so as to derive the maximum possible benefit from the compressed air stored in each. There is also a material modification of these calculated results, due to the processes not being truly isothermal, as assumed, and so on. Proper allowance being made for these limitations, a formula might be derived, in the same manner as above, to completely cover the more complicated conditions, but as we are concerned here only with laying down the principles involved, it is unnecessary to go further into details, particularly as these are accurately determined by experiment.

In the above analysis, as is necessarily the case with all theoretical considerations relative to mechanical apparatus of this character, certain assumptions were made to furnish a basis from which to start. Hence, it should always be remembered that the formulæ derived must be inter-

preted, for any given case, in the light of the modification of these primary assumptions which the nature of the installation or the character of the apparatus used, may involve. With this understanding, the above reasoning affords a logical and sound theoretical basis, not only for determining the correct proportions of new types of equipment, but also establishes a criterion, by means of which the shortcomings of incorrectly designed installations may be discovered.

Past and Present Conditions.

It is our effort tonight to show, not that the air brake has advanced relatively to the requirements, but that it has endeavored to keep pace with the developments of locomotion; in other words, how and why we are able today to control and stop a train in approximately the same distance as when the weight and length of the train was less than one-fourth of that today and the speed correspondingly slower, which is quite an accomplishment since the length of the trains and the volume of air employed have rendered this vastly more difficult as to service control and the weight to the extent that it would require at least twice the distance in which to stop if the old brake had to be used with present day conditions.

In addition to the increased weight and speed of trains, there are of course, increased number of parallel tracks and frequency of trains.

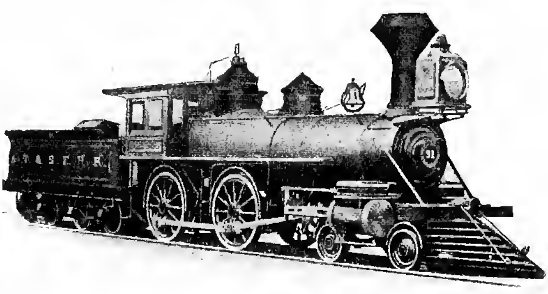


Fig. 3. American Type of Locomotive, 1879.

These always bring with them braking problems quite as difficult of solution, and as necessary to be solved, as those which preceded them, particularly as the tendency is to neutralize or lower the value of many of the factors involved in producing and realizing retarding forces.

It is difficult for one who has not given the subject careful thought to realize the great changes in railroad equipment and operative requirements which have taken place since the introduction of the air-brake, but it is only necessary to review briefly these past and present conditions in order to appreciate the necessity for a similar development and improvement of the apparatus used for controlling trains under these new conditions.

The following comparative tabulations comparing the conditions existing from 15 to 20 years ago and those of today with regard to extent of territory covered, capital involved, traffic handled, and so on, will perhaps illustrate the conditions that now have to be faced better than the mere statements which have just been made.

RAILROAD DEVELOPMENT FROM 1889 TO 1909.

	1889.	1909.	Increase, per cent.
Miles of line	153,385	234,182	52.7
Miles of track	195,958	340,000	73.5
Net capital, etc...............	$7,366,745,000	$13,508,711,000	63.3
Passengers carried	472,171,000	880,764,000	86.5
Tons freight carried	539,639,000	1,486,000,000	175.3
Locomotives, number	29,036	57,220	97.0
Freight cars, number	829,885	2,113,450	154.6
Employees, number	704,743	1,524,000	116.2
Employees, compensation	$389,785,564	$1,003,270,000	157.4
Electric railways		50,000	

Locomotives.—The weight on drivers has increased since the air-brake was invented, from 25,000 pounds to 400,000 pounds.

The drawbar pull of locomotive has increased, since the air-brake was invented, from 10,000 pounds to 100,000 pounds.

The total weight of locomotives at the present time is as high as 700,000 pounds.

Working steam-pressure has increased, since the air-brake was invented, from 125 pounds to 225 pounds.

Passenger Cars.—Weights have increased from 20,000 pounds to 150,000 pounds.

Freight Cars.—Light weight of car has increased from 12,000 pounds to 50,000 pounds.

Capacity has increased in the last twenty years from 40,000 pounds to 150,000 pounds.

Passenger Trains.—Schedule speeds have increased from 30 miles per hour to 65 miles per hour.

The energy contained in a five-car train of cars having an average light weight of 30,000 pounds per car, running at a speed of 35 miles per hour, is 6,200,000 foot-pounds; of cars having an average weight of 127,000 pounds running at 65 miles per hour is 90,000,000 foot-pounds, or nearly fifteen times as much.

Freight Trains.—Train length has increased from 15 to 130 cars; total weight has increased from 300 to 4,500 tons and in certain places in the country as high as 6,000 tons.

To take an actual example illustrating what is involved in the handling of a modern high-speed passenger train, the following figures are taken from the official report of the Emergency Brake Tests on the Lake Shore & Michigan Southern Railway near Toledo in 1909:

LAKE SHORE EMERGENCY BRAKE TEST.

Types of Vehicles Used.	Weights. Pounds.	Tons.
Locomotive—Pacific type	388,000	194.0
Buffet car	149,000	74.5
Dining car	140,000	70.0
Sleeping car average	125,000	62.5

ENERGY IN TEST TRAINS.

Make up of train	2 Loco.—10 Cars	1 Loco.—6 Cars
Train weight—pounds	2,068,000	1,180,000
Train weight—tons	1,034	590
Energy at 40 M. P. H., foot-pounds.	116,816,000	66,595,200
Energy at 40 M. P. H., foot-tons	58,408	33,298
Energy at 60 M. P. H., foot-pounds.	262,836,000	149,839,200
Energy at 60 M. P. H., foot-tons	131,418	74,920
Energy at 80 M. P. H., foot-pounds.	467,264,000	266,380,800
Energy at 80 M. P. H., foot-tons	233,632	133,190

KINETIC ENERGY* IN TRAIN OF 2 LOCOMOTIVES, 10 CARS OF 75 TONS WEIGHT EACH—TOTAL TRAIN WEIGHT, 2,276,000 LBS. OR 1138 TONS.

Speed	40 M. P. H.	60 M. P. H.	80 M. P. H.
Foot-pounds	127,811,200	287,575,200	511,244,800
Foot-tons	63,906	143,787	255,622

Figs. 3 and 4 present a tangible evidence illustrative of both extremes of the locomotive development indicated in the tabulations just given. The view of the American type of locomotive (Fig. 3), representing standard practice of 1879 is in marked contrast with the enormous Mallet Compound Locomotives (Fig. 4) now being introduced for heavy grade service in various parts of the country.

Similarly the progress in passenger car construction is graphically illustrated by comparing the typical passenger car of 1872 (Fig. 5), with the modern all-steel Pullman cars (Fig. 6), which are being built at the present day.

All the figures which have been given report the maximum conditions of past and present-day practice. As the application of the airbrake has made this enormous increase in weight of vehicles, speeds and length of trains possible, it is fair to assume that the stopping power of the brake should logically be increased in the same proportion so that the stop should be no longer now than formerly.

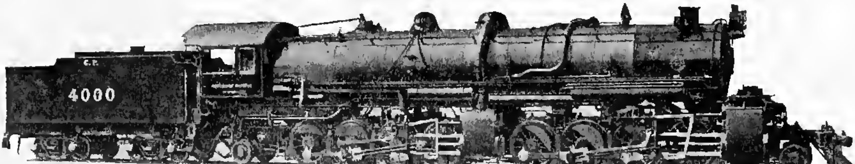


FIG. 4. MALLET ARTICULATED LOCOMOTIVE—ATCHISON, TOPEKA & SANTA FE RY., 1909.

* Kinetic energy in train of 2 locomotives, 10 cars of 75 tons weight each—at speed of 80 M. P. H. is sufficient to raise 1 ton to a height of over 48 miles.

A concrete example will show forcibly just what this increase in weight and speed means to the operating department if it is to accomplish such an admittedly desirable and necessary result. Under the former conditions the factor of safety in train handling was none too large and it is therefore imperative that we should be able to control modern trains under present existing conditions at least as safely and efficiently as formerly. To do this for five 150,000 pound coaches, running at 65 miles per hour, it is necessary to provide means for controlling over 105,000,000 foot-pounds of energy as compared with about 6,000,000

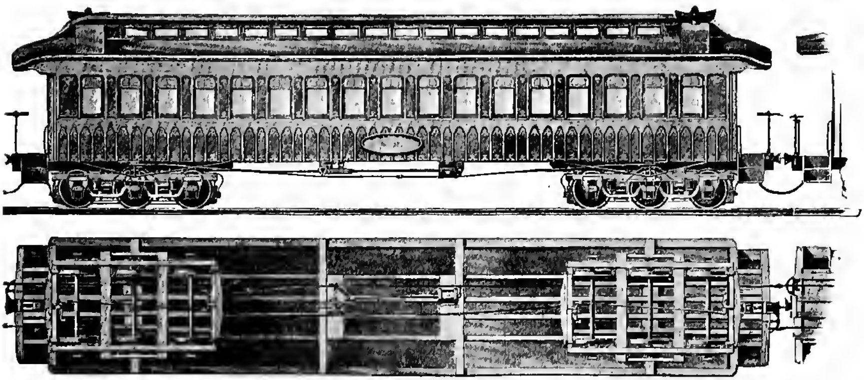


FIG. 5. PASSENGER CAR, 1872.

foot-pounds which was all that the brake of the early 70's was called upon to control with a train of five 30,000-pounds cars running at 35 miles per hour. When the locomotive used with each train is considered, the total energy in the modern train becomes 162,000,000 foot-pounds, as compared

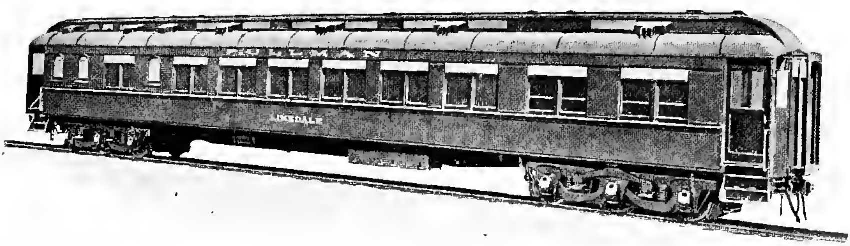


FIG. 6. ALL-STEEL SLEEPING CAR, 1909.

with 9,800,000 foot-pounds for the train of 1870. It is not surprising, therefore, that the air-brake art demands thoughtful consideration from trained and experienced minds if the railroad traffic of today is to be

handled with a safety and efficiency even equal to that of the days when the total energy to be reckoned with was one-sixteenth as great. Here again is found another close resemblance between the conditions of acceleration and deceleration, for while it is not especially difficult to increase the speed of a train from 30 miles per hour to 40 miles per hour, it requires the expenditure of a vastly greater amount of energy to increase its speed from 60 miles per hour to 70 miles per hour. In like manner, for any given increase in speed the additional amount of work required from the brake increases in geometrical, not arithmetical, ratio. If, therefore, the improvements for the heavier trains and higher speeds of today permit of stopping in about the same distance as could be done with the brake of forty years ago and the trains of that period, we should congratulate ourselves for having held our own.

The mere power necessary to accomplish this is indicated by the fact that the total maximum force exerted by the push rod of the 6 in. brake cylinder of the early equipment was 1700 lbs., while with the 18 in. brake cylinder used on the heaviest coaches of today a maximum pressure on the push rod of 26,650 lbs. is obtainable.

From the above it will be apparent that many features must now be considered which did not exist when the brake was first invented, particularly on the physical side of the problem. For example, the amount of work required per square inch of brake shoe surface is vastly greater. This is a condition seldom noticed and yet of great significance, as the following comparison will show:

In the report of one of the earliest brake trials in the history of continuous brakes, made on the Midland Railway, near Newark, England, in 1875, and since known as the Newark trials (see London *Engineering*, June and July, 1875), we find that the best brake performance there recorded was by a train of fifteen, 21,000-lb. (average) four-wheel carriages, fitted with a primitive form of the Westinghouse Automatic Brake, one cast-iron brake shoe being used on each wheel. The best stop was made from a speed of 52 m. p. h. the highest that could be obtained, in 18 seconds. This corresponds to the performance of 15.5 foot tons (1 ton = 2000 lbs.) of work per brake shoe per second. In the classic Westinghouse-Galton tests, which followed about three years later, the four-wheel experimental van used weighed 18,200 lbs. and was fitted with two brake shoes per wheel, and from 52 m. p. h. speed a stop was made by the experimental van alone in 11½ seconds. Here the work done was only about 9 foot tons per brake shoe per second.

In 1875 the standard passenger coach used on the Pennsylvania Railroad weighed 39,300 lbs. and had four wheeled trucks. To stop such a car from 52 m. p. h. in 18 seconds required only 12.33 foot tons of work per brake shoe per second, or less than that required of the brake on the Midland train, although the Pennsylvania car weighed 18,300 lbs. more. This is, of course, due to the fact that eight brake shoes were available to do the work, as compared with four on the Midland train. Contrast with the above a modern Pullman car weighing 160,000 lbs. and having six-wheel trucks. Assuming that from a speed of 52 m. p. h. the stop

could be made in 18 seconds, the work done would be 33.5 foot tons per brake shoe per second, or over twice that of the Midland train, notwithstanding that there are twelve brake shoes to do the work instead of four. But modern express train speed may be expected to run frequently as high as 75 m. p. h., and to make a stop from this speed in, say, 35 seconds (which would be about the best we could expect of the modern brake equipment) would require 35.8 foot tons per brake shoe per second, or not much more than when a stop of 52 m. p. h. is made in 18 seconds. But to have the same absolute safety under modern conditions as existed in 1875 would require the stop to be made in at least the same distance and time, and to stop a 160,000-lb. car from a speed of 75 m. p. h. in 18 seconds would require 69.6 foot tons of work per brake shoe per second or about 4½ times that in the case of the Midland train. (What this would be with four-wheeled trucks will be appreciated.) Even if we could use two brake shoes per wheel instead of one, we would still have over twice as much work to be performed by each brake shoe per second if the trains of today at the speeds now attained in high speed service are to be relatively as safe as the trains of thirty years ago. Furthermore, the use of two brake shoes per wheel is rapidly becoming a necessity, not only on account of the great amount of work to be performed by each brake shoe, but also because the brake shoe pressures required by modern conditions of high speeds and heavy cars are becoming so great that in emergency applications a heavier pressure is brought to bear on the axle and journals by the brake shoe acting on one side of the wheel only than is imposed by the weight of the car resting on that wheel.

The tremendous significance of this increase, is, we believe, but faintly appreciated by those who have not had occasion to investigate this aspect of the question. We have today the cast-iron brake shoe practically as it was thirty years ago. This brake shoe must now do four times the amount of work by frictional resistance to the rotation of the wheel, as formerly. We may say "Why not quadruple the pressure per brake shoe"? But it must be remembered that when the brake shoe pressure is multiplied by four, the actual retarding force is by no means quadrupled, for we are then overlooking three vital adverse factors, viz., the effect of increased pressure, speed, and temperature on the coefficient of friction between the wheel and the shoe. Exactly how great an effect these may have depends, of course, on the conditions of the individual test considered, but that it is considerable is proven by the fact that a stop from a speed of 75 m. p. h. in 35 to 40 seconds, instead of 18 seconds, is considered good, although we are today using about four and a half times as much pressure per brake shoe as at the Newark trials.

We should mention that in the above no account is taken of the rotative energy of the wheels. If this is considered, it is evident that the figure for the modern conditions will be still more in excess of those of the past, on account of the wheels being heavier and there being a greater number per vehicle.

Again, the difference in air pressure required to apply and release the brakes is by no means as easily obtained today as when trains were short. The air supply required for short trains with small brake cylinders was obtained with compressors of much less capacity than it is now necessary to employ: witness, the 6 in. air compressor of the early days of the brake, with its capacity of not over 15 cu. ft. of free air per minute, as compared with the cross compound compressors now used, which have approximately 125 cu. ft. capacity. The reason for this is apparent, for it required, not so very long ago, about 25 to 30 cu. ft. for a full application; now 300 cu. ft. is required. In general, therefore, it may be stated that the brake which would satisfactorily meet the requirements of past conditions falls short of the maximum efficiency which it should be possible to attain in proportion to the increase of the requirements of present day service over those of the past. The force of this is apparent when we make the same comparison between the locomotives and cars of the two periods. This review of the conditions and what is involved, which is by no means exhaustive, will serve to give an idea of the magnitude of the problem. How we have solved the various stages of this problem, as they presented themselves, will be best shown by a consideration of the features and functions of the improved brake apparatus that was developed to meet the conditions just explained.

Development of the Brake.

The operating conditions prevailing about 1870 were very different from those of the present time: then the tracks were not of the character of today and not suitable for such heavy and fast traffic; in fact, neither the locomotive nor the cars were capable of it, therefore, the brake required was something better than a hand brake, which was obtained when the straight air brake (Fig. 2) was applied to the equipment. This term implies that compressed air is used as a direct force from the main reservoir supply of the locomotive through direct piping to the brake cylinders on the vehicles to apply the brakes, simply requiring a valve on the locomotive to admit air to the brake pipe and brake cylinder in order to apply the brakes, to hold it there when admitted and to exhaust it when desiring to release the brakes. An early form of this apparatus is shown in Fig. 7. The air pump is one of the first forms to come into general use, the so-called "trigger" or "jigger" valve motion and square piston rod being recalled no doubt, by many here present. The brake valve was the simplest form of three-way cock. The hose couplings were "butt end," male and female, which necessitated there being a male and a female coupling at each end so that a connection between cars might always be made.

This equipment had many good qualities and a very large degree of flexibility, that is, the increase or decrease of the pressure or braking power, was under the control of the operator to a marked degree. But it had shortcomings which made it unsuitable for use on trains of any considerable length on account of the time required to apply and

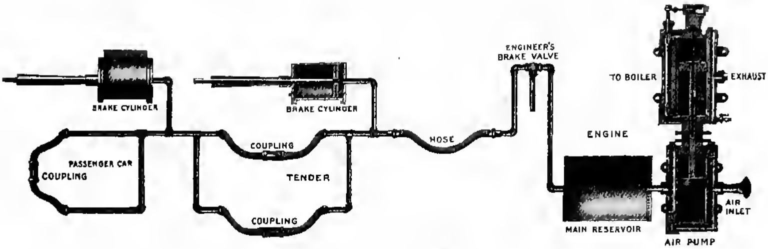


FIG. 7. THE STRAIGHT AIR BRAKE.

release the brake and the unequal braking effort throughout the train. More important still, the factor of safety was low, as no warning was given in the event of the hose coming uncoupled, and a parted train meant no brakes. Thus it is seen that it lacked the first essential of an efficient brake, which is, that it must be its own "tell-tale." That is, if an accident occurs to the system, it must result in a brake application instead of a loss of the brake.

Plain Automatic Air Brake.

In the natural process and development of railroads, the requirements became more exacting and it was evident that the straight air brake was not only unsuitable for the reasons just mentioned, but that it lacked essential features. It became more important than ever that the brake should apply automatically, in case of the train parting. This was so fundamentally necessary that even if the flexibility of the straight air brake had not already been lost to a large extent by the lengthening of the trains, it would have had to be abandoned because of the infinitely greater safety inherent in a brake of the "automatic type." Therefore, the straight air brake, having served its purpose as an advanced agent of something better, gave way to the automatic brake, which afterwards came to be called the "plain automatic brake" to distinguish it from a later type that locally reduced the brake pipe pressure, thus producing what is called "quick action."

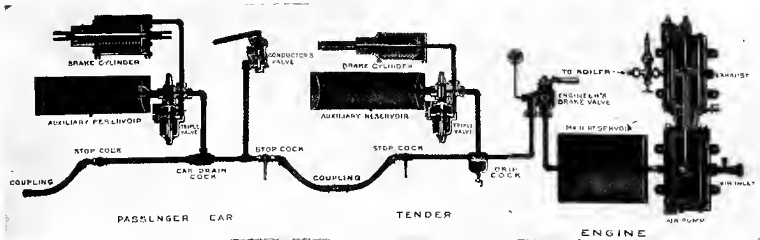


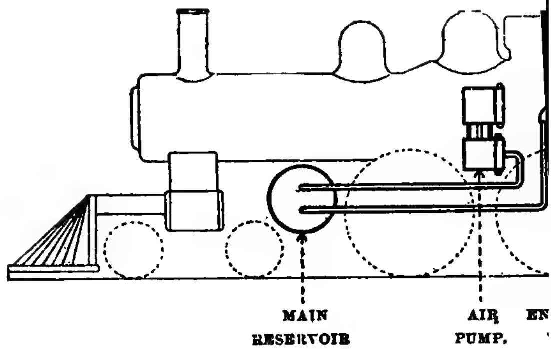
FIG. 8. THE "WESTINGHOUSE" PLAIN AUTOMATIC AIR BRAKE, 1872.

The first form of this brake, probably the greatest advance ever made in the art, was invented and introduced by Mr. George Westinghouse in 1872 (Fig. 8).

The automatic action of the brakes was accomplished by means of indirect application of the brakes through the medium of a valve device called a triple valve and an auxiliary storage reservoir which were added to the brake cylinder on each car. All of these valves were connected together by a continuous pipe called the brake-pipe; with flexible connections between the cars; this pipe being charged with air whenever the brakes were in operating condition. By this means, the auxiliary reservoir was charged with compressed air for braking purposes on the vehicle to which it was attached; therefore, it was no longer necessary to transmit the air from the locomotive to the vehicle when an application of the brakes was desired. From what has been said, it is plain that the triple valve must be the essential mechanical element in such a system and that it must possess the three functions of charging and recharging the auxiliary reservoir and of applying and releasing the brakes in accordance with variations in the air pressure carried in the brake pipe; the medium for producing such operation as desired being for all ordinary cases a manually operated brake valve on the locomotive.

The operation of the triple valve to apply the brake is brought about by reducing the brake pipe pressure, thus creating a differential of pressure in the auxiliary or braking reservoirs throughout the train; this reducing of the brake pipe pressure below that of the auxiliary reservoir pressure, permits the auxiliary reservoir pressure to force the triple piston and its slide valve to application position, in which position the brake cylinder outlet to the atmosphere is closed and a port opened from the auxiliary reservoir to the brake cylinder, when the auxiliary reservoir pressure will also reduce equally with that of the brake pipe into the brake cylinder and apply the brake. It is, perhaps, needless to say that these applications could be either partial or full; thus the brake possesses graduating features so far as the application is concerned. To release the brake, it is necessary to create a differential in the reverse order, that is, the brake pipe pressure must be increased above that of the auxiliary reservoir, when the triple valve will be forced to release position, opening the brake cylinder to the atmosphere and thus releasing the brake, and also opening the necessarily restricted passage from the brake pipe to the auxiliary reservoir that it might again be recharged to full braking pressure. There was no graduating feature in the release of this brake, therefore one of the elements of flexibility possessed by the straight air brake was lost, but, as has been said, this feature had already been very much reduced in value by the lengthening of the train.

Thus, through the use of triple valves, the air brake became automatic, which term applies to that *application* of the brakes which occurs through any material depletion of pressure from any cause in the brake pipe and auxiliary reservoir pressure, either at the will of the engineer, by hose parting, burst hose, leakage, or at the instance of the train crew so that this system very materially increased the factor of safety and permitted the use of air brakes on longer passenger trains and on the already existing freight trains in a way that was not possible with the straight air brake equipment.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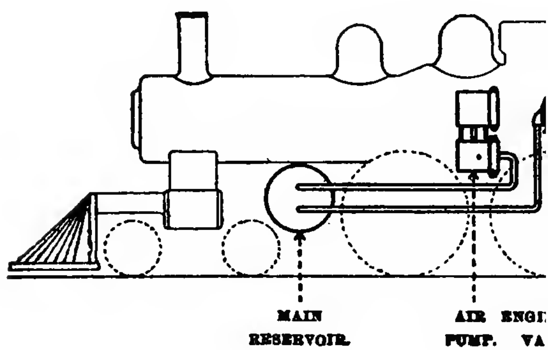
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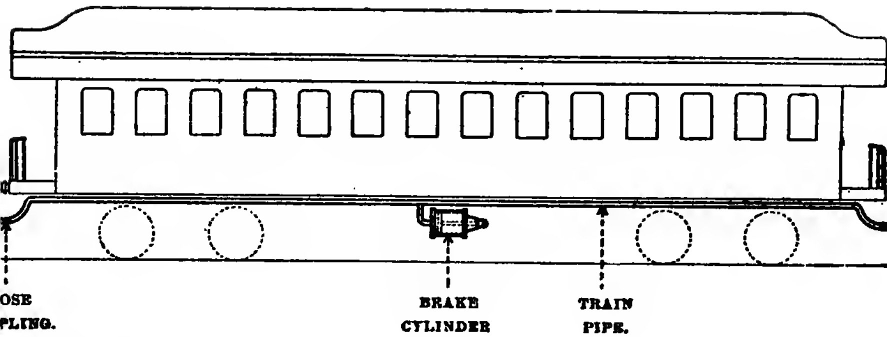
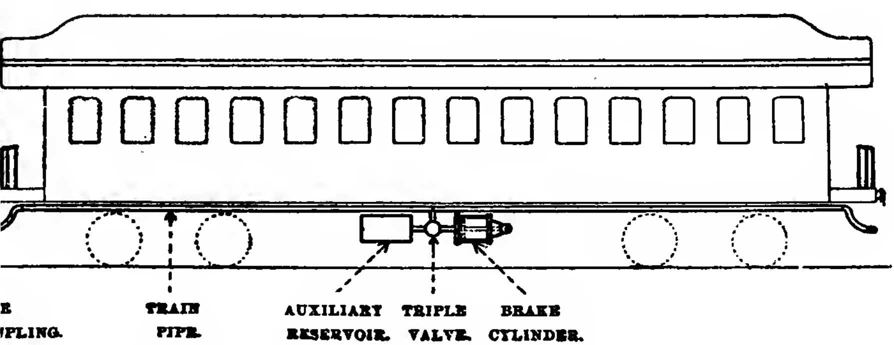


AS APPLIED TO A TRAIN.



S APPLIED TO A TRAIN.

It is generally thought that the invention of the valve mechanism solved the problem of automatic brake operation and this is exceedingly unfortunate, for of an importance second only to the apparatus itself were the fixing of the conditions under which the brake would operate properly, namely:

1st.—The percentage of braking power to light weight of car.

2nd.—The times the cylinder value could and should be multiplied to advantage and without detrimental results—that is, the fixing of the leverage ratio.

3rd.—The proportion of auxiliary reservoir volume to brake cylinder volume.

4th.—The percentage of braking power per pound of cylinder pressure.

5th.—The amount of reduction of brake pipe pressure to produce equalization and the time in which it should be done.

These things required a great amount of thought, experiment, and practical experience, and when Mr. Westinghouse had worked all these out, the brake itself, the governing factors of its operation, its installation and manipulation were practically perfect and have never been improved upon. We regret to say, however, that these things have often been changed and ignored to such an extent that the operation and efficiency have been seriously impaired, and while much has been said and written from the standpoint of stopping the train only, little or no consideration is given to the above mentioned factors, which are vital to the every day operation of the brake and make possible and permissible a much greater stopping power than can be used if these factors are not utilized. In fact, satisfactory operation and proper stopping power, as we have already pointed out in the consideration of the Fundamental Principles of Brake Design, are absolutely dependent upon them.

Quick Action Automatic Air Brake.

This plain automatic brake was a great improvement in many respects over straight air brake, but chiefly from an emergency or safety standpoint, for much of the flexibility (that is, ability of the operator to increase or decrease the cylinder pressure at will and for any number of times in rapid succession) for ordinary service brake operations had to be sacrificed. This brake served the purpose fairly well while trains were short and speeds, weights, and frequency low, but as these factors changed, *its* limitations became more and more apparent, particularly with reference to emergency operation. The application was too slow with long trains, *and for* reasons differing only in degree from those which had affected the straight air brake. Thus, when a quick application was attempted, the shocks were great, nor was the stop as short as required. The reason for this slowness of operation was because the air in the brake pipe could not be quickly and uniformly reduced throughout its whole length; this, because of increased volume, frictional resistance and the necessity of its traveling to the one outlet, which was

through the brake valve at one end of the train. This limitation was overcome by the invention (in 1887) of the "quick action" triple valve and the equipment with which it was used came to be known therefore as the Quick-Action Automatic-Brake (Fig. 11). The "quick-action" triple valve was identical with the plain triple valve as far as service operations were concerned, but differed from it in emergency in that

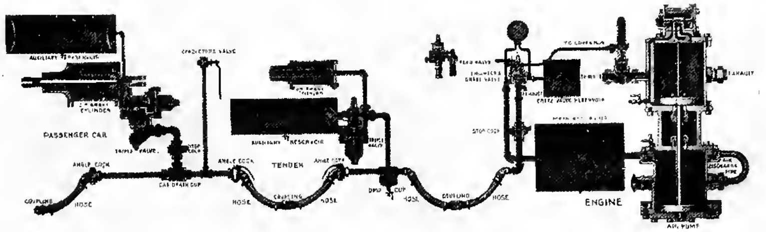


FIG. 11. THE "WESTINGHOUSE" SYSTEM QUICK-ACTION AUTOMATIC BRAKE, 1887.

it automatically vented air from the brake pipe locally on each car. The rapid brake pipe reduction thus resulting is transmitted to the next triple valve and from it serially in the same manner to all the valves in the train, thereby reducing the time of full application to about one-sixth of what is inherent with plain triple valves on a 50-car train, and shocks were therefore correspondingly lessened and stops shortened. The reason for this is that the brake pipe reduction with the plain triple valve took place at only one point in the train instead of fifty as with the quick-action valve.

The feature of serial venting of the brake pipe was so important that a second feature of this brake system, which the first mentioned made possible, was, and is today, overlooked by many, and perhaps we should say is not rated at its true value. We refer to the then possible attainment of a different and higher braking power for emergency than for service applications. Up to this time the cylinder pressure and retarding force then attainable had been the same for both service and emergency applications, but now, since the brake pipe pressure vented could be, and, as a matter of fact, was vented into the brake cylinder with one form of the device, the pressure therein was materially increased whenever quick action took place. As this, with the comparatively small cylinders of that day, raised the pressure from 50 lbs. equalization to 60 lbs. from an initial brake pipe pressure of 70 lbs., it will be seen that the increase in braking power was 20 per cent. This, for passenger service, was allowed to remain. This was warranted because these trains were shorter than freight trains and the cars more rigid and of greater length, the measure on the one hand being property, the other both property and human life. This difference of braking power was utilized

in another way in freight cars, and wisely so. Instead of permitting this service percentage of braking power to remain the same as before, it was changed from 70 per cent. on 50 lbs. cylinder pressure to 70 per cent. on 60 lbs. cylinder pressure. This made the brake much more flexible for service applications and reduced shocks, etc., because of the lower braking power for given reductions. From this it will be seen that to the automatic and graduating features of the brake two others were added, namely, serial quick action and difference or increase in braking power between service and emergency applications. All four of these are now generally recognized (though we are sorry to say not appreciated as they should be) as being fundamentally essential in a brake worthy the name. Moreover, these four features have had and still have great possibilities of extension and development. We would here again call attention to the wonderful adaptability of the original combination of brake cylinder, triple valve, and auxiliary reservoir to the ever-increasing need of a more powerful, and what naturally follows, a more flexible brake. *It is truly remarkable that through all subsequent improvements not one of the original functions of the triple valve has been discarded, but that they have been extended and expanded and many new functions added.*

So far the apparatus employed was the same for both passenger and freight cars, but the still greater frequency of trains, heavier vehicles, and higher speeds made it necessary to provide means whereby a still greater stopping power for passenger service might be available when needed, particularly for emergency applications. This was possible only by increasing the air pressure, since any other method would have made the brake too severe for low speeds; in other words, the percentage of braking power per pound of cylinder pressure was already as great as practical operation would permit.

The High Speed Brake.

It was thought, however, that to increase the brake pipe pressure sufficiently to get desired braking power would result in unpleasant or dangerous shocks, slid or flattened wheels, and other damage from the high brake cylinder pressure obtainable; therefore, this was not done until the valve known as the "high speed reducing valve" was perfected in 1894. The principles utilized by this type of apparatus had been thoroughly demonstrated by the classic Westinghouse-Galton tests in England in 1878. These tests showed that, while the adhesion between the wheel and the rail,—which causes the wheels to persist in their rotation,—is practically uniform at different speeds, the friction between the brake-shoe and the wheel,—which acts as a resistance to the rotation of the wheel, and thereby stops the train,—is considerably less when the wheels are revolving rapidly than when they revolve slowly. It was thus demonstrated that a greater pressure not only could be safely applied to the wheels by the brake-shoes, at high speeds, but also that such considerably greater brake-shoe pressure *must* be applied to the wheels at high speeds, in order to then resist the motion of the train

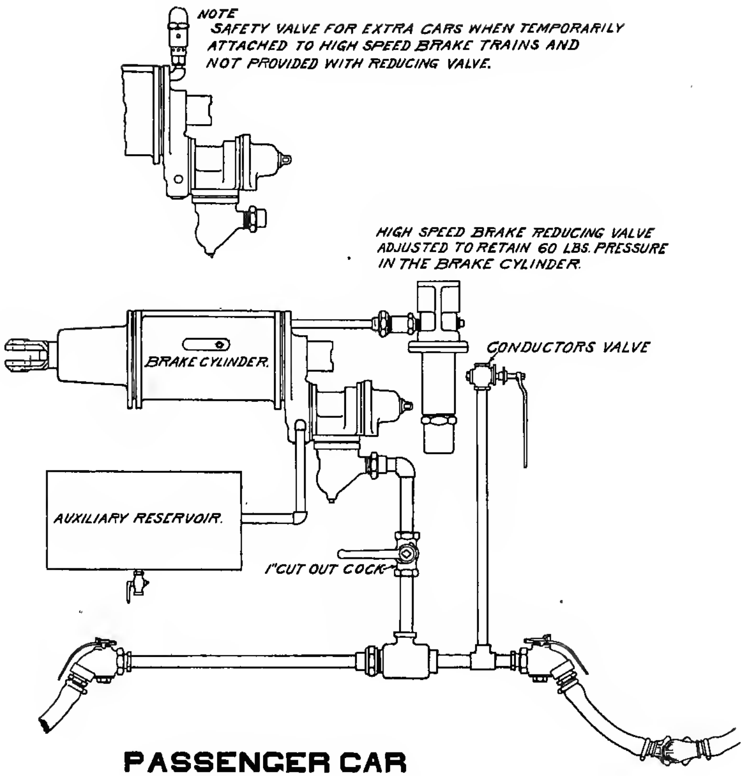


FIG 12. HIGH-SPEED PASSENGER BRAKE.

as effectively as it is resisted with a more moderate brake-shoe pressure at low speeds. This was accomplished by the use of a higher brake pipe air pressure with the standard Quick-Action apparatus, with only the addition of a High-Speed Reducing Valve attached directly to the brake cylinders. This device was designed to limit the brake cylinder pressure obtainable during a service application of the brakes to what was considered safe and necessary, but when an emergency application of the brakes was made, to permit the brake cylinder pressure to rise to a considerably higher value than the maximum permitted in a service application, and then to cause a gradual reduction of brake cylinder pressure, quite slow at first, but becoming more rapid, so as to proportion, as far as possible, with such a device working on a fixed range, the blow-down of brake cylinder pressure to the reduction in speed as the stopping point is approached. Superior stopping capacity was obtained as already stated, by increasing the brake-pipe air pressure from the generally adopted 70 pounds, as used with the Quick-Action Brake equipment, to 110 pounds, which in emergency applications and with the sizes to brake

cylinder then in use would give about 85 pounds cylinder pressure instead of about 60 pounds, or, in other words, raise the nominal percentage of braking power from 90 to 125 per cent. of the weight of the vehicle.

With this improved equipment when an emergency application was made, full cylinder pressure (85 pounds) was quickly obtained, but was automatically reduced to 60 pounds and held at this point by means of the automatic reducing valve. Thus, if the stop was long enough, the initial nominal percentage of braking power was 125 per cent., while the final was 90 per cent., but the actual retardation of the train kept fairly constant due to the difference in the retarding power of the shoes at high and low speeds already mentioned. Though the co-efficient of brake-shoe friction was known to be less at high speeds than at low speeds, it was predicted by many that much wheel sliding would result from raising the nominal power above 100 per cent. of the light weight of the car, but, on the contrary, wheel sliding was lessened and naturally so when the situation is analyzed.

These improvements were adopted by practically all the first class railroads of America and the results have fully justified their use, not from the standpoint of increased safety alone, but as a dividend earning asset. For example,—in suburban service, a good brake is worth more than a good engine as a schedule maker. This combination, with the quick action triple valve, is known as the high speed brake. As with this innovation, the brake for passenger and freight service parted company never more to be the same, it will be necessary for us to consider the future development of these brake equipments in the order of 1st, *The Locomotive Brake:* 2nd, *The Passenger Car Brake;* and 3rd *The Freight Car Brake.*

The Locomotive Brake.

In the early days of railroading practically no attention was paid to the necessity for braking power on the engine and tender on account of the service conditions prevailing and fear of flattening and slipping the driving wheel tires. A little later straight air brakes, similar to those under the cars, were applied to tenders; then the driver brake was added and later (after the automatic brake came into use), as it became necessary to utilize every possible means for obtaining braking power, the truck brake, thus forming the complete brake installation. Such service as double-heading next led to the substitution of the quick action triple valve for the plain triple valve on the tender, it being necessary to risk occasional occurrences of undesired quick action rather than suffer any loss in the ability to transmit quick action from the head engine to the train. In the case of passenger locomotives, the development of the high speed brake equipment resulted in the addition of the high speed devices to the locomotive equipment. Then for freight engines used in special service, such as grade work, switching, etc., the need for the independent control of the locomotive brakes became apparent, which led to the application of the straight air brake on such locomotives, which, in combination with the automatic brake, greatly increased the efficiency

of the brake apparatus. Fig. 13 shows the apparatus required in order to completely equip an engine and tender with the devices necessary to accomplish the desired results. It will be noted that all of the above changes have come about as additions to existing equipments forming a series of progressive steps in the attempt to provide a combination of devices permitting a maximum of safety and flexibility in train handling.

When further improvements became necessary, the undesirability of adding further to the existing equipments became apparent and it was resolved to depart from the previous lines along which improvements had been made and to design outright an equipment which would combine the functions of several pieces of apparatus and include the features required of a brake which should meet the requirements arising from present-day conditions—this equipment to cover all kinds of service and classes and weights of locomotives. The immediate result of such a simplification would be to establish a uniformity of practice in regard to equipments on different locomotives and in different parts of the country, which would be appreciated not only by the management and purchasing agents, but make possible the attainment of the best possible results by the engineer with a minimum of time and expert training, because the operation and manipulation of only a single equipment would need to be learned.

Features of the ET Locomotive Brake.

This brake, probably known to most of you, is called " THE 'ET' LOCOMOTIVE BRAKE EQUIPMENT," (Fig. 14), and, as will be pointed out, includes all of the advantageous features which have been worked into previous equipments, eliminates many of the undesirable features inseparable from former types, and provides many additional operative features which have been long desired but hitherto unobtainable with other types of equipment. It may be of interest to point out more in detail what some of these features are.

The space occupied by the equipment on a locomotive has been materially reduced, as many of the pieces of apparatus necessary with most of the advanced types of former equipments have been done away with. For example. the equipment includes one automatic brake valve, one independent brake valve, one feed valve, one reducing valve, one distributing valve, one safety valve, two gages, and the brake cylinder taking the place of the automatic brake valve, straight air brake valve, two feed valves and reversing cock, straight air reducing valve, two double check valves, two high speed reducing valves, two mountain cocks, two retaining valves, three auxiliary reservoirs, two triple valves, tender drain cup, and the brake cylinders all of which apparatus would have to be used in making up a complete equipment of the old standard, as shown in Fig. 10, while the results would still fall far short of approximating the operation of the " ET " equipment.

The new equipment is adapted for all classes of engines and all kinds of service and requires carrying but one size of operating devices in stock, since the only difference made in the equipment when applied to the different sizes of locomotives is in the size of brake cylinder employed.

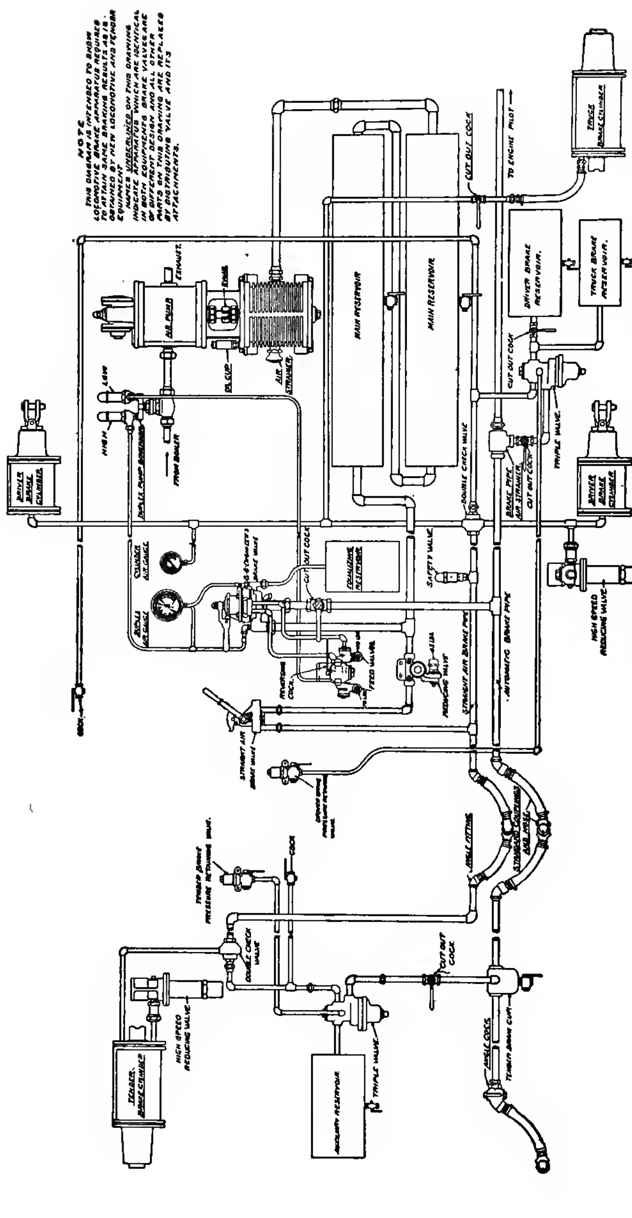


FIG. 13. LOCOMOTIVE BRAKE EQUIPMENT, COMPRISING COMBINED AUTOMATIC AND STRAIGHT AIR, HIGH SPEED, DOUBLE PRESSURE CONTROL AND INDEPENDENT RELEASE ATTACHMENTS.

The brake valve has very large ports, which the increased length of train and larger auxiliary reservoirs have made necessary. It is also constructed so that the wear of the rotary valve and seat has been more evenly distributed and the valve can therefore be operated with greater ease and maintained at less expense.

All of the valves used with the equipment, *i. e.*, the brake valves, feed valves, reducing valves and distributing valve, are mounted on permanent bases or brackets to which the pipe connections are made once for all so that it is not necessary to break any pipe connections in order to remove the valves for cleaning or repairs. Consequently, if the engine should come into the round house with the feed valve or distributing valve needing attention, it could be replaced by another valve in a very short time, without causing any delay and avoiding any chance of getting dirt inside the valves, which might happen if the inspection or repairs were attempted with the valve in place on the locomotive.

The feed valve used with the equipment is of improved design and is provided with a hand wheel on the adjusting nut moving between two adjustable stops, so that a change from standard pressure to high-speed brake pressure, or vice versa, can be made by simply turning the hand wheel from one stop to the other.

The safety valve used in connection with the distributing valve is of improved type and is specially arranged so as to operate in a manner similar to the high speed reducing valve when an emergency application of the brake is made.

The independent brake valve is provided with a double return spring which returns the handle from release to running position and from quick application to slow application position, thus relieving the engineer of the necessity for careful attention to these points when handling the independent brake.

The brake on the locomotive can be used entirely independent of the train brakes, or in conjunction with them, at any and all times, as with the present equipment, or the engine brakes can be applied without applying the train brakes, by the use of the independent brake valve. It is unnecessary to point out in detail the advantages of this in connection with switching and handling long trains, especially on grades. The locomotive brake can be released without releasing the train brakes. The train brakes can be applied without applying the locomotive brake, by simply holding the independent brake valve handle in release position while applying with the automatic brake valve, if, for any reason, it should be necessary to prevent the application of the brakes on the locomotive. The locomotive brakes can be released without releasing the train brakes. The advantages of this are many; for instance, if the drivers of the locomotive should slide, the pressure can instantly be released from the cylinders. In grade work, if there should be any danger from overheating the tires, the driver brakes can be prevented from applying or they can be released if they are applied and in descending grades the locomotive and train brakes can be alternated by first applying the train brakes and preventing the locomotive brake from applying, then applying the locomotive brake and

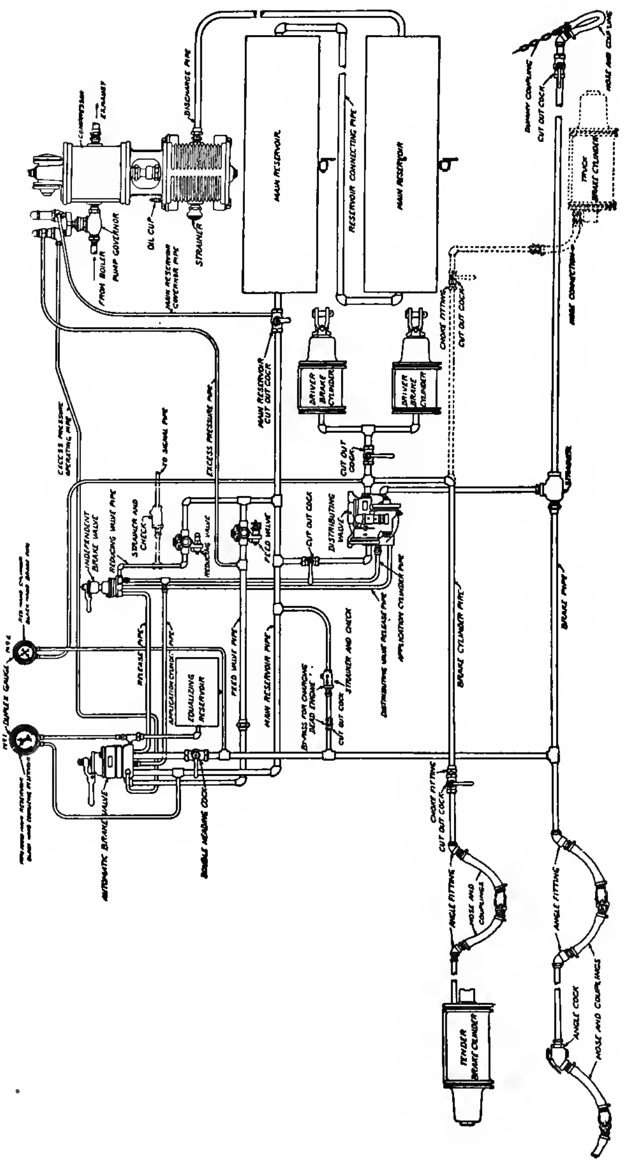


FIG. 14. THE ET LOCOMOTIVE BRAKE.

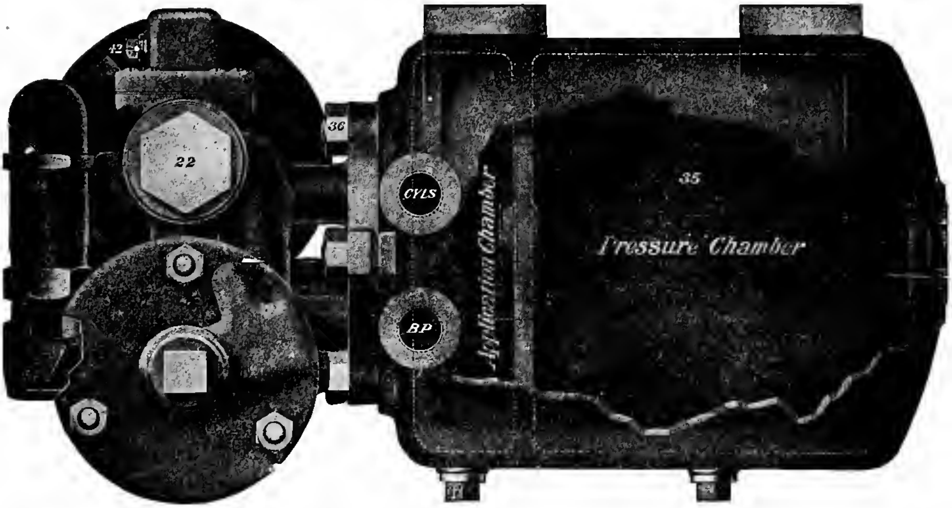


FIG. 15. THE DISTRIBUTING VALVE AND DOUBLE CHAMBER RESERVOIR.

holding the train by means of the locomotive while the train brakes are released and the reservoirs recharged, then again applying the train brakes and releasing the driver brakes—obtaining in this way much better control down the grade which permits of a higher average speed being maintained than would be possible otherwise. The train brakes can be released and the engine brakes held on keeping the slack bunched until the train brakes have released. The locomotive brakes can then be either let off quickly and entirely, or can be graduated off. This is of the greatest importance in releasing the brakes on a long freight train, as it prevents the great retardation which is still taking place at the rear end from pulling the train in two after the head brakes have released. Its advantage in passenger service is also obvious, as the engineer can release his train brakes and graduate his locomotive brake off just as the stop is being completed, thus making an accurate stop without shock, as the trucks have been permitted to right themselves before the train comes to a standstill.

The operation of the equipment is such as to discourage overcharging, with consequent stuck brakes, by making it more necessary for the engineer to return to running position at the proper time, thus insuring proper manipulation of the brake valve.

It provides for a graduated release of the locomotive brakes, in connection with the new high speed brake.

If it is necessary to hold the train for a short time, as for a station stop on a grade, the independent locomotive brake alone can be used, permitting the train brakes to be fully recharged and enabling the engineer to start promptly when the signal is given.

Full braking power is obtained at any time desired, that is to say, the equalizing point is not changed by leakage in the cylinders or their connections, or by long or short piston travel.

For a given reduction, uniform pressure is obtained in all brake cylinders on the locomotive regardless of difference in piston travel or leakage which may exist.

Any brake cylinder pressure obtained, whether partial or full application, is maintained constant against leakage up to the capacity of the compressor, whether the application is made by the independent or the automatic brake valve. This feature is one of vital importance in a locomotive brake in particular, as all will recognize who are familiar with the great difficulty experienced in keeping the locomotive brake cylinder packing leathers even fairly tight.

During emergency applications about 30 per cent. higher brake cylinder pressure is obtained on the locomotive than the maximum for service operations of the brake. This has long been an accepted principle of operation for all car brake equipments, but heretofore not provided for on the locomotive—the vehicle which, of all others, should take full advantage of this principle on account of the large proportion of braking power which it contributes to the total for the train, and the consequent danger of flattening the drivers or slipping the tires in service applications if the braking power of the locomotive largely exceeds that of the loaded cars.

The holding position of the automatic brake valves serves as an automatic pressure retaining valve, enabling the engineer to hold any desired pressure in the locomotive brake cylinders.

If the brake valve handle is returned to lap position after making a release of the train brakes, as is often done in making a two application stop or when slowing down for a signal, it cannot be left there by mistake and forgotten, as the locomotive brake will remain applied and draw the engineer's attention to his oversight—a protective feature worthy of note.

When double-heading, the man on the second engine can operate his locomotive brake entirely independent of the other brakes in the train, so that, in case of necessity, he is able to release his driver brake if the tires become overheated or the drivers slide and can assist the head man in alternating the locomotive and train brakes while descending grades.

It is thus seen that the greatest braking unit in the train is under the complete control of the engineer without regard to what is being done with the train brakes at any time.

Operation of the "ET" Locomotive Brake.

As the operative principles embodied in the "ET" brake have become recognized as fundamentally required by the conditions of modern high-speed passenger service, as well as locomotive service, it may not be amiss to state briefly the manner in which these desirable operative features have been secured. The air used in the brake cylinders for applying the brakes on the engine and tender comes directly from the main reservoir through the distributing valve, Fig. 15. The

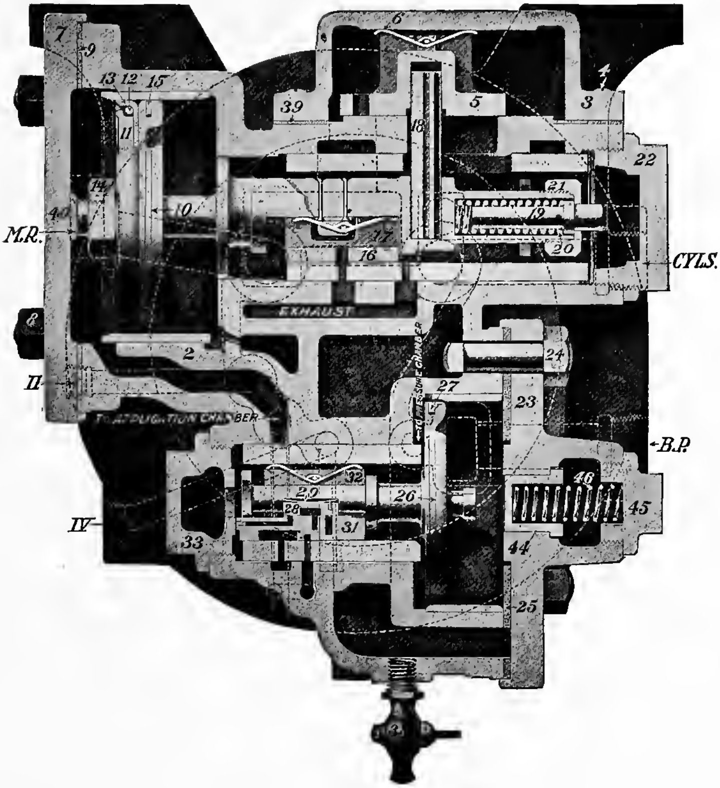


Fig. 16. Section of Distributing Valve.

flow of air from the main reservoir to the brake cylinders, when applying the brakes, is controlled by a slide valve in the distributing valve. (See Figs. 16 and 17.) A second slide valve, attached to the same piston stem as the first, controls the flow of air from the brake cylinder to the atmosphere when releasing the brakes. The entire control of the locomotive brake, therefore, reduces to the controlling of the movement of the *application* piston which operates the supply and exhaust valves. This is accomplished by so arranging the distributing valve that brake cylinder pressure always acts on one side of the application piston mentioned above, while the chamber on the other side is subject to various degrees of pressure, according to the manipulation of the brake valve. This chamber is called the *application cylinder*. In order to apply the brakes it is only necessary to admit compressed air into this application cylinder, thus increasing the pressure on that side of the application piston above that in the brake cylinders on the other side of the piston. This causes the piston to move, closing the exhaust ports and opening the supply valve and allowing air to flow to the brake cylinders.

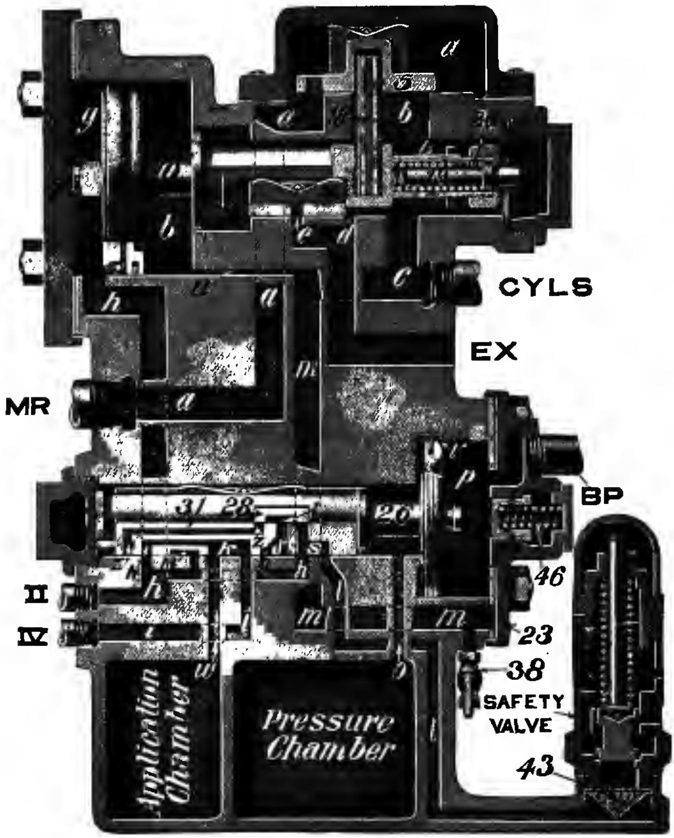


FIG. 17. DIAGRAMMATIC SECTION OF DISTRIBUTING VALVE AND RESERVOIR. RELEASE POSITION.

As soon as the brake cylinder pressure has increased to slightly above that in the application cylinder on the opposite side of the application piston, the difference of pressure returns the piston and its slide valves to lap position, preventing further flow of air to the brake cylinders. It will, therefore, be seen that the same pressure will be obtained in the brake cylinders whether there are few or many, large or small, whether the piston travel is long or short, equal or unequal, and whether the brake cylinders are air tight or leaking badly. This is because the main reservoirs furnish an unlimited supply of compressed air which has access to the brake cylinders until such time as it has increased the pressure therein up to that which is in the application cylinder. Furthermore, so long as the pressure in the application cylinder is held constant, the brake cylinder pressure will be maintained practically constant as well. For suppose

there is sufficient leakage in the brake cylinders and their connections to cause a drop in pressure to take place, after the supply valve has lapped. This lowers the pressure on the brake cylinder side of the application piston below that which still remains constant on the other side of the piston, which, being then the higher, will again move the application piston to application position and re-open the supply port, permitting sufficient air to flow from the main reservoirs to the brake cylinders to replace that lost by leakage and restore the original pressure. This operation will continue so long as the application cylinder pressure remains unchanged and, in fact, where the brake cylinder leakage is excessive, the application piston will assume a balanced open position, permitting a constant flow of air into the brake cylinders from the main reservoir to compensate for the constant escape of air to the atmosphere, thus maintaining the brake cylinder pressure constant up to the capacity of the air compressors.

When the pressure in the application cylinder is reduced below that in the brake cylinders, the higher brake cylinder pressure will then move the application piston and its attached slide valves back to release position, opening the exhaust port and permitting air to escape from the brake cylinders until their pressure has become reduced to slightly below that remaining in the application cylinder, which then moves the application piston and its valves back to release lap position, in which further flow of air from the brake cylinders is prevented. Thus, the brakes may be partially or entirely released by partially or entirely exhausting the air from the application cylinder. Compressed air is admitted to the application cylinder from two sources; 1st, from the reducing valve (set at 45 lbs.) through the independent brake valve and the application-cylinder pipe which leads to the application cylinder. When the independent brake valve is placed in application position, air flows directly from the reducing valve to the application cylinder. When the independent brake valve is in lap position communication to the application cylinder is cut off and when in release position the application cylinder pipe is open through the independent brake valve direct to the atmosphere.

By the use of this brake valve, therefore, the locomotive brakes can be applied or released without interfering with the automatic brake system in any way. There is, however, a pipe connection from the independent to the automatic brake valve so that normally, when operating the independent brake (the automatic brake valve then being in *running* position), the independent brake valve handle may be placed in running position to release the brakes, the exhaust then passing through the independent and automatic brake valves to the atmosphere. The operation just described will be recognized as similar to that of a straight air brake and, as a matter of fact, it displaces the straight air portion of the old combined straight and automatic brake equipment, and gives, without the installation of release valves, double check valve, cut-out cocks, etc., an independent locomotive brake, whether or not the automatic brake is being used.

During an automatic application of the brakes, the air delivered to the application cylinder comes from the second source of supply, viz., the large compartment of the double-chambered reservoir of the distributing valve, called the pressure chamber. The flow of air from the pressure chamber to the application cylinder (which is in free communication, except when in emergency applications, with the smaller compartment of the double chambered reservoir, called the application chamber) and chamber is controlled by a slide valve (equalizing valve) and graduating valve, moved by a piston (the equalizing piston). The equalizing piston is exposed to brake pipe pressure on one side and pressure chamber pressure on the other. It therefore controls the flow of air from the pressure chamber to the application cylinder and chamber in a similar manner as the flow of air from auxiliary reservoir to the brake cylinder is controlled by the triple valve piston in ordinary car brake equipments. It will, therefore, be unnecessary to describe in detail how a given brake pipe reduction causes a certain fixed amount of air to be admitted from the pressure chamber to the application chamber and cylinder, except to point out that the volume of the latter is fixed and practically air tight, so that the relation of the volumes involved is always the same, and the pressure therein not subject to variation due to changes in piston travel or leakage. Therefore, the pressure obtained in the application cylinder for a given reduction in brake-pipe pressure is always the same, and therefore, as already explained, the brake cylinder pressure obtained is constant likewise. This explains why a single equipment may be used for large or small locomotives alike, and, when the possibilities of independent operation of locomotives and train brakes are considered, why the equipment is adapted to all classes of engines in all kinds of service.

During automatic service applications, as well as when operating the independent brake, the safety valve on the distributing valve is connected to the application cylinders. This safety valve is of improved design and of large capacity so that ample and adequate protection is afforded against brake cylinder pressures higher than that determined by the setting of the safety valve.

When the automatic brake-valve handle is placed in either release or running position, the equalizing piston and its valves are moved back to release position, as in a triple valve, the exhaust cavity in the equalizing slide valve connecting the application chamber and cylinder to the distributing valve release pipe. This, instead of always being open to the atmosphere, as in the case of a triple valve exhaust, leads through the independent brake valve (when in running position) to the automatic brake valve and is open only in the running position of the latter. There is only one position of the automatic brake-valve handle, therefore, viz., running, which will release the locomotive brakes and this only when the independent brake valve is in running position.

While the automatic brake valve handle is in release position during a release of the brakes, the locomotive brakes still remain applied, keeping the slack bunched and permitting the car brakes to get the start in releasing. A new position (Holding Position) is also provided on the

automatic brake valve, which is exactly the same as running position except that the distributing valve exhaust port is closed. If it is desired, therefore, to still further hold the locomotive brakes applied while releasing the train brakes and recharging the auxiliary reservoirs, it can be done by returning the automatic brake valve handle from release to "holding" position, and the locomotive brake can then be graduated off by successive movements of the automatic brake valve handle between holding and running position and in this way the automatic brake valve is made to perform at once the functions of a pressure retaining valve and a straight air brake valve.

When an emergency application is made, all connections to the application chamber of the distributing valve are blanked and equalization takes place between the pressure chamber and the application cylinder only. This not only results in 30 per cent. higher brake cylinder pressure being obtained, but, furthermore, the safety valve is at the same time connected to the application cylinder through a restricted port and air from above the automatic rotary valve flows through a small port in this valve to the application cylinder pipe and application cylinder, thus prolonging the time of blow-down of application cylinder pressure (and consequently of brake cylinder pressure) similar to the operation of the high speed reducing valve on car equipments.

For locomotives running in double heading service the plain cap on the equalizing cylinder portion of the distributing valve is replaced by the Quick Action Cap, as shown in Fig. 18. The function of this cap corresponds to that of the quick action parts of the triple valve, viz., to vent a certain amount of air from the brake pipe to the brake cylinders when an emergency application of the brakes is made and thus assist in transmitting the serial quick action to the succeeding brakes in the train. With modern long locomotives and cars, and especially when double heading service is considered, such provision as this is necessary in order to insure the maximum protection against loss of serial quick action.

It will be seen from what has been said regarding this equipment for locomotives that the flexibility and safety features of the brake have been greatly increased and that it is not only capable of taking care of the necessities of the present, but that ample provision has been made for the requirements of the future as far as they can be foreseen.

The Passenger Car Brake Equipment.

It will be remembered that from the time of the development of the high speed brake, it was apparent that the brake for passenger service and freight service would have to be worked out along radically different and distinct lines,—speed, frequency and weight being the governing factors in the one case, and length of train and a great difference between empty and loaded weights of cars, the vital factors in the other.

For a considerable period the high speed brake equipment already referred to, fully accomplished the purpose for which it was designed and provided a train control approximately as efficient for the trains to which it was applied as was that of its predecessor for the earlier conditions.

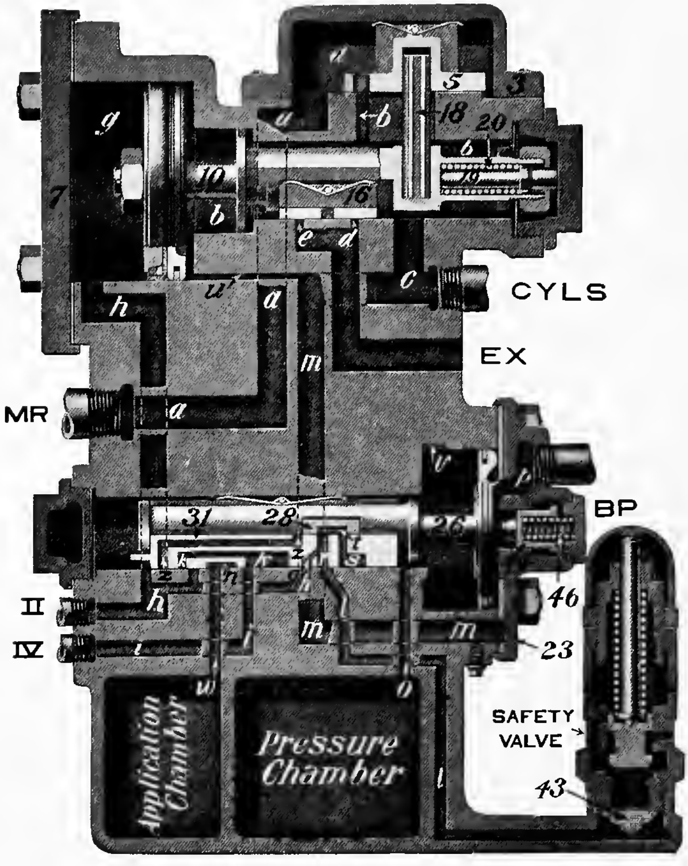


FIG 18. DIAGRAMMATIC SECTION OF DISTRIBUTING VALVE WITH QUICK ACTION CAP—EMERGENCY POSITION.

But as time went on, further changes in conditions, which necessarily go with progress, reduced the comparative efficiency of this brake, and to a large extent neutralized the improvements that had been made from the older forms. For it is a remarkable fact that all improvements in rolling stock construction and train operation have been in a direction that has made train control more difficult, and we have no hesitation in saying, unless radical departures are made from present practice in other railroad equipment, that in spite of all the improvements we can make in the air brake, the controlling of trains, particularly with regard to stops, is going to fall behind past results, therefore, the best is none too good. The increased weight of passenger trains and particularly the running of such trains at high speed, has so increased the energy to be dissipated that to make a stop in the same time and distance as with a lighter train, it is necessary to use still higher cylinder pressure; obtain the braking

power as promptly as circumstances will permit; and hold the maximum pressure obtained through to the end of the stop, because the work to be done and the duration of the stop causes a heating of brake shoes and wheel tires and so on, all tending to lessen the effectiveness of a given brake cylinder pressure.

In addition to the increased weight and speed of trains, there were, of course, an increased number of parallel tracks and frequency of trains. These always bring with them braking problems quite as difficult of solution and as necessary to be solved as those which preceded them, particularly as the tendency is to neutralize or lower the value of many of the factors involved in producing and realizing retarding forces.

Features of the Improved Brake for Passenger Cars.

A careful analysis of these conditions and problems with deductions checked by experiment and test, notably at Albany; then after these tests were analyzed, of others at Absecon, and these again followed by others, and also by installations in actual service, led to a new design of brake embodying all the features of the old and a number of others, some considered essential from a safety standpoint, others very important in the way of properly meeting operating conditions, reducing the personal equation, and in materially increasing the value and adding to the already great earning power of a good and an efficient brake. The development of this type of brake apparatus marks a notable departure from the lines along which previous improvements had been made, in that, instead of securing the desired new features by the addition of accessory devices to the already existing apparatus, opportunity was taken to incorporate not only the novel features but also the improvements which it was possible to make in the design of the standard apparatus into a single triple valve structure, thus reducing the number of separate devices comprised in the equipment to a minimum. The features added to those already possessed by the preceding brake equipments were:

1st.—Quick recharge of the auxiliary reservoirs, to offset longer trains and larger cylinders and reservoirs. This is accomplished in the design of the triple valve in such a way as to make a larger feed groove unnecessary; thus insuring prompt application and preventing depletion of auxiliary reservoir pressure.

2nd.—The quick service feature, to compensate for increased length of train and bring about more prompt, uniform and certain application of the brake.

3rd.—The graduated release feature, to neutralize the shock effects of long and heavy trains, to add to the flexibility of the brake by making it possible to graduate the brakes off, as well as on, thus eliminating the loss of time required and risks incident to "two applications stops." This feature makes possible a proper and heavy application at the commencement of the stop and low cylinder pressure at the end, therefore saving much time and reducing wheel sliding. In conjunction with the quick recharge feature it also permits making a great number of successive

applications without exhausting the air supply, thus rendering it practically impossible for a train to run away on a grade. In fact, if the pump stops or its capacity is too low to furnish the air necessary to properly control the train, it will be brought to a standstill until the main reservoirs are replenished. This feature also insures against the very dangerous possibility of the engineer lapping the brake valve after a partial release and forgetting it; if he does, the train will be brought to a standstill.

4th.—More efficient protection against too high cylinder pressure being obtained during a service application, 1st, by limiting the cylinder pressure; 2nd, by using a reducing valve of proper capacity; thus wheel sliding is reduced and the proper margin maintained between the power of service and emergency applications.

5th.—Better mechanical design resulting in more uniform wear of parts, and ease of access for removal or repairs.

6th.—For the same brake pipe pressure carried, a much higher cylinder pressure is obtained in emergency, which pressure is retained during the complete stop, thus materially shortening the stops and adding greatly to the safety of the trains.

7th.—The ability to obtain quick action and emergency cylinder pressure after a considerable service application has been made, thus insuring maximum braking power at a time when it is most likely to be needed, viz., after a service application has been made and an emergency arises. This is most likely to happen at places where a service application for slow down has already been made.

The reasons why this higher cylinder pressure is necessary and permissible will be explained later. If, for any reason, this higher pressure is not desired or is not expedient, the same cylinder pressure as is now obtained from 110 lbs. brake pipe pressure with the old high speed brake can be had with 90 lbs. brake pipe pressure—quite a profitable feature and important in many ways, not the least of which is that it leaves quite a wide margin for special and future necessities. It must not be forgotten in this connection, that when this high braking power is provided by the brake apparatus, there must be a corresponding provision made for increased strength of foundation brake gear and adaptation of bearings, trucks and rigging to the increased stresses thereby developed.

Not only were these operative features added to the brake, but it was modified in other ways; for example: 1st, smaller auxiliary reservoirs than previously employed were used with a given size of brake cylinder for the service operations, while for emergency operations, another and larger reservoir is added to the service reservoir and the volume of both used to give a much higher cylinder pressure than before—the reason for this has already been pointed out; 2nd, the braking power is calculated from 50 lbs. cylinder pressure instead of 60 lbs., as was formerly the case;—and 3rd, while ample and efficient means are provided to limit the cylinder pressure to what is predetermined for service applications, in emergency a higher cylinder pressure is obtained and held until the stop, that is, the reducing valve is operative only in service applications. The im-

portance of these modifications is very far reaching, but time will not permit of an extended explanation of the reasons or even mentioning all that is involved. We will at least attempt to show that the reasons are sound and the gains from a legal and safety standpoint down to that of maintenance such that, if understood, they cannot be ignored.

In two ways there had come into existence a considerable change from the original design of passenger car brake apparatus. The auxiliary reservoirs had become larger in proportion to the brake cylinder volumes to compensate for the lessened value of the air vented from the brake pipe to the brake cylinder in emergency applications, because of increased size of brake cylinder with the brake pipe volume remaining practically constant. The leverage ratio had been increased also because of reluctance to use large cylinders as cars increased in weight. This continued until operation in service was adversely affected with regard to shoe clearance and the graduating features of the brake.

To properly meet the requirements of service, it has become necessary to limit the leverage ratio employed to 9 to 1, and to base the braking power upon the service brake cylinder pressure actually obtained, and to use an auxiliary reservoir bearing the same proportion to the brake cylinder volume as in the original brake design. An additional emergency reservoir compensates for the difference which there came to be between the added emergency pressure obtained from the brake pipe with the small brake cylinders of the earlier equipments and the very large cylinders of today.

In fact, once the necessity for this provision was established, it became evident that it could be carried further and the additional reservoir allowed to compensate, not only for the difference mentioned, but to give a still increased emergency brake cylinder pressure and, incidently, be made use of during service applications to obtain other functions such as furnishing a practically unlimited air supply, for obtaining a quick recharge of the auxiliary reservoirs, and permit of a graduated release—something heretofore impossible with an automatic system and characteristic of straight air and vacuum brakes only.

Not only is a higher pressure obtained in emergency than heretofore possible with a given pressure carried, but this pressure is held from the beginning to the end of the stop, the conditions making this desirable and possible being hereinafter mentioned.

It should not be inferred, however, that this high pressure is obtained during service applications, for this cannot occur for two reasons: 1st, the "emergency" or supplementary reservoir does not come into use during service applications; and 2nd, the maximum cylinder pressure which might be obtained from a high pressure carried in the ordinary service application auxiliary reservoir is prevented by means of a reducing valve which operates only in service applications, keeping the pressure down to what is predetermined, safe and necessary, but is automatically cut out when the emergency application is made. We may say that we believe the successful use of the high speed brake requires an ample protection against excessive cylinder pressure for service ap-

plications, for it certainly would not be good engineering to take the thousand and one chances of individual wheel sliding, etc., in service, to the same extent as in emergency applications. We do not want to be understood as being committed to 60 lbs. as a maximum cylinder pressure permissible for service applications, but as giving illustration to what is self-evident; namely, that when once this pressure has been determined upon, the means used should be adequate to so limit it. In this connection we cannot too emphatically state that one of the most valuable features in connection with the new brake for passenger service is that the same stopping power, as with the old brake, can be obtained from 70 lbs. pressure carried instead of 110 lbs.; therefore, a brake equal to that at present in use and employing 110 lbs. brake pipe pressure can be had by the use of 70 lbs. pressure, thus leaving open the choice of taking advantage of the lower pressure and stopping in about the same distance as at present, or employ the same pressure as at present, and materially shortening the stop. In any case it will be seen that we have a brake of very wide range and extended adaptability.

There naturally arises, independent of the service operation of the brake, a question as to the implied departure from the principle of reducing the braking power as the speed decreases after an emergency application, but an understanding of the factors involved and the changes in the equipment and conditions that have occurred since this principle was first enunciated will show that there is no real departure, but that the principle itself is as much a requirement as it ever was. As a matter of fact the required protection against excessive braking force toward the end of the stop commonly exists to a marked degree, in that the brake shoe itself now acts as a substitute for the former high speed reducing valve. This is because the coefficient of friction is neither so high nor is it increased as the speed reduces to the same degree as before on account of the much greater amount of work the shoe has to perform, due to the increased weights and speeds.

Moreover, because of the greater rigidity of cars and foundation brake gear, greater resistances and losses, longer wheel base (which lessens the shifting of weight from one truck to another during a stop), greater uniformity of brake shoe metal employed and of braking power on all cars, the nominal braking power employed can be much greater than ever before; in fact, it is absolutely necessary if trains are to be stopped in the same distance now as when the conditions of forty years ago prevailed. A natural inference from these statements would be that, notwithstanding the improvements already referred to, stopping power has not been increased in proportion to the requirements. This is a fact; for, as has already been pointed out, with all the improvements mentioned, the trains of today cannot be stopped in any shorter distance than was possible at the time of the Westinghouse-Galton tests in 1878.

Thus we see that the principle laid down by Mr. Westinghouse at that time is not violated in the least, but, on the contrary, its truth is being made more apparent from year to year, the difference being that instead of 360 per cent. braking power being required before it becomes

necessary to reduce the pressure during a stop from 60 miles per hour speed, as the report of the above tests shows, it is more likely that 500 per cent. nominal braking power will be required before the reducing principle needs to be considered at such speeds, and correspondingly higher for greater speeds.

Nor should it be overlooked, in this connection, that it was necessary to pass through a stage of development and experience along these lines before such conclusions could be reached. It may therefore be seen that in this, as well as in other developments mentioned before, experience and conditions have joined hands in bringing about the recent changes in air brake practice for passenger cars. We have in mind a number of tests made during the past few years in which the nominal braking power was 180 per cent. to 220 per cent., and this constantly maintained until the end of the stop for all speeds, without flattening wheels; in fact, the only result was to shorten the stop as compared with those of lower braking power.

That this question of high braking power may not be misconstrued, it may be well to state that the nominal braking power and the retarded force actually realized on the wheel are two different things, and we would earnestly recommend that all interested, if they have not already done so, read a paper entitled "What Stops a Moving Train?" which was presented before the Western Railway Club and published in their proceedings of May 15th, 1906, which throws considerable light on the subject. (See Appendix.)

To illustrate what is meant by this difference in nominal and actual braking power, it is sufficient to state that with a rail adhesion of 25 per cent. (which is low) and a coefficient of friction of 7 per cent. (which is high for present maximum speeds, materials and weights), a nominal 150 per cent. braking power will give a retarding force of only 10½ per cent. of the weight of the vehicle—still far short of being equal to the adhesion of the wheel and the rail, which is the force compelling its rotation. This naturally leads to a consideration of

Braking Power and Wheel Sliding.

The amount of braking power which can be applied to a car wheel, without causing it to slide, depends upon two things: 1st, the total amount of frictional force developed between the wheel and the rail; and 2nd, the total amount of frictional force developed between the brake shoe and the wheel; such forces as journal friction, friction between wheel flanges and rail, etc., which have more or less effect under certain conditions being disregarded.

As has been frequently pointed out, the maximum retarding effect is obtained when the brake shoe friction is as high as possible and yet not greater than the rail friction or "adhesion" and the greater the "adhesion" the greater the possible retardation. The effectiveness of a brake of high efficiency, utilizing to the greatest practicable extent the possibilities of a high "adhesion" coefficient, is illustrated in the case of the automobile brake. When the former does exceed the latter and thus causes the wheel to slide, a decided loss in retarding effort results.

As the *percentage of braking power* in terms of the light weight of the car and the *retarding force* are no longer convertible terms, the latter cannot be measured by such percentage, but is determined by the proportion of brake shoe pressure actually converted into frictional force between the shoe and the wheel, which varies inversely with the speed, pressure and time.

In each of the two prime factors, viz., rail friction or "adhesion" and brake shoe friction, mentioned above, there are two secondary factors concerned. The frictional force between the wheel and the rail, which is the force acting to keep the wheel rotating, depends upon the weight carried by the wheel and the coefficient of friction between the wheel and rail. The frictional force between the brake shoe and the wheel depends upon the pressure exerted upon the brake shoe, and on the coefficient of friction between the shoe and the wheel. In the problem of properly adjusting the braking power so that a maximum retarding effect may be obtained without sliding the wheels, there are, therefore, four variable factors to be considered, viz., weight on wheel, coefficient of rail friction, brake shoe pressure and coefficient of brake shoe friction.

That this problem is really a most complicated one will be realized on further consideration of each of these variable factors.

1st.—*The weight carried by any one wheel* can easily be determined for any given car, when it is not moving. But when in motion and the brakes are applied, new forces are introduced which so affect the distribution of pressure on the wheels that it becomes impossible to determine the exact weight carried by each wheel at different periods of the stop. The tendency of the car body to pitch forward and the tilting of each truck results in a heavier pressure being exerted on the forward truck and on the forward axle of each truck. The amount of these pressures depends not only on the rate of reduction in speed, but also to a large extent on the action of the cars ahead and behind the one considered.

2nd.—*The coefficient of friction between the wheel and the rail* is also a more or less uncertain quantity. While practically independent of the speed, it varies with the condition of the rail surface, and may have widely different values at different points on a given line of track, or under changing conditions of weather. This coefficient is also doubtless affected by the pressure, its value decreasing slightly as the pressure increased, but the exact relation is not yet thoroughly understood.

The frictional force exerted by the brake shoe depends upon the pressure exerted upon the brake shoe and the coefficient of friction between the brake shoe and wheel.

3rd.—*The brake shoe pressure* is the resultant of the pressures exerted by the brake beams and hanger links. As the wheels and shoes are constantly wearing, the inclination of the hanger link, when the brake is applied, is constantly changing. This exerts a variable influence on the pressure transmitted from the foundation brake gear through the brake beam to the shoe, so that in actual service the determination of the exact amount of pressure acting on the brake shoe is by no means a simple problem.

4th.—*The coefficient of friction at the brake shoe* is a variable quantity of the most complex character, depending upon the quality of the two metals in contact, the relative speed of the two surfaces in contact, the time during which the shoe remains applied, and to a certain extent on the pressure. The kind of metal used for the brake shoe is the factor of greatest influence, since it determines not only the initial coefficient of friction but also the character of the variation which the coefficient of friction undergoes during the progress of the stop.

A determination of the proper amount of braking power to be used, which will give a reasonable margin of safety from wheel sliding, involves, therefore, a consideration of these four variable factors, viz., weight on wheel, coefficient of rail friction, coefficient of brake shoe friction and the pressure on the brake shoe. Of these, the last is the only factor of the four over which we have any control, and that only partially; and it is this factor which must be properly decided upon in advance so as to give the maximum braking effect, consistent with safety from wheel sliding under the extremes determined by the other three factors involved. This is rendered the more difficult by the fact that these coefficients of friction between the wheel and rail and between the wheel and the shoe are not only different, but each is constantly changing during a given stop. Therefore, the statement that a car has so much "per cent. braking power" is only a convenient way of specifying the calculated amount of pressure applied to the shoes from the foundation brake gear. It does not convey any information regarding the existing margin of safety against wheel sliding, and very little as to the retarding force available to overcome the momentum of the car or train of cars. The best that can be done is to thoroughly analyze the factors as outlined above and be governed by the general law in the case, expecting that extreme deviations will at times produce undesirable results, which, however, is by far the less of the two evils confronting us, viz., failure to properly control the train, particularly at times when danger is imminent; or, to properly control the train at all times, but with, perhaps, occasional wheel sliding.

A factor not mentioned up to this point is the rotative energy of the car wheel due to its inertia. Evidently, this would tend to keep the car wheel rotating, even if the brake shoe friction was equal to or slightly exceeded, even, the rail friction. This introduces another factor, varying with the square of the speed, requiring consideration at all speeds, but of considerable importance at high speeds. By neglecting to consider it, however, the error will always be on the safe side, as regards wheel sliding, as its effect is to keep the wheel rotating when otherwise it would stop.

In what has been said with reference to wheel sliding, and the conditions under which it is to be expected, no mention has been made of influences affecting the problem outside of the car itself. In other words, the statements made and conclusions reached up to this point have been concerning a *single car,* running alone. When coupled to other cars in a train, the circumstances are entirely different, for each car is then

affected by the other cars to a greater or less extent and it frequently happens that the influence of one car upon another in the same train is much greater than all the other forces existing on that car. For example, the statement is often made that the most prolific cause of wheel sliding is *unequal braking power* in a train. What is meant by unequal braking power on two cars? Plainly, it must mean that the retarding force, the force which brings the cars to a standstill, is not the same on the two cars. A strain is, therefore, set up at once by the higher braked car tending to stop it much quicker than the lower braked car, and, if this strain becomes sufficiently great, the adhesion of the wheels on the higher braked car to the rails is overcome by the pull or push of the lower braked car and they are skidded. It is important to notice just here that the fault was not with the car on which the wheels were skidded, but with the lower brake car on which the brakes were not doing as much in proportion to their load as were those of the higher braked car. The last statement then raises the question, "What is necessary to overcome this tendency of one car to run ahead of the other and force the latter 'off its feet'?" There must be the same retardation, or rate at which the speed is being decreased on each car. This can only be brought about when the proportion of retarding force to the momentum of the car is the same for each car. In other words, within reasonable limits, the braking percentage of the weight of the cars should be the same, the cylinder pressure obtained and retained should be the same, the composition of the brake shoes should be the same, and the nearer each wheel comes to carrying the same weight, the more uniform will be the retardation. These are not all the factors, but are illustrative of what is involved, and it is because they are more nearly uniform today than ever before, and because many variable factors are reduced to a minimum in the more recently developed brake for passenger cars that it is possible to utilize much higher nominal and actual braking power than ever before.

Another thought that may assist in distinguishing between nominal and actual braking power or retarding force is that if we brake a car at 100 per cent. of its weight, it does not stop dead the instant the brake is applied for the reason that the actual resistance against which this braking power is acting is not the weight of the car, but the kinetic energy of this weight which is proportional to the weight and to the square of the speed at which it is moving. Therefore, as already stated, 100 per cent. braking power is only a convenient way of stating the number of pounds calculated braking force acting on the shoes. It does not mean that the momentum of the car is opposed by an equal resistance in the opposite direction, nor does it even mean that 100 per cent. of the weight of the car is being exerted as retarding force, for, as has been pointed out, the actual retarding force, is entirely different from the brake shoe pressure.

. Probably the thought uppermost in the minds of most of you now is: "What would be the effect of such a high nominal braking power, as is proposed, at low speeds and as the speed decreases during a stop from

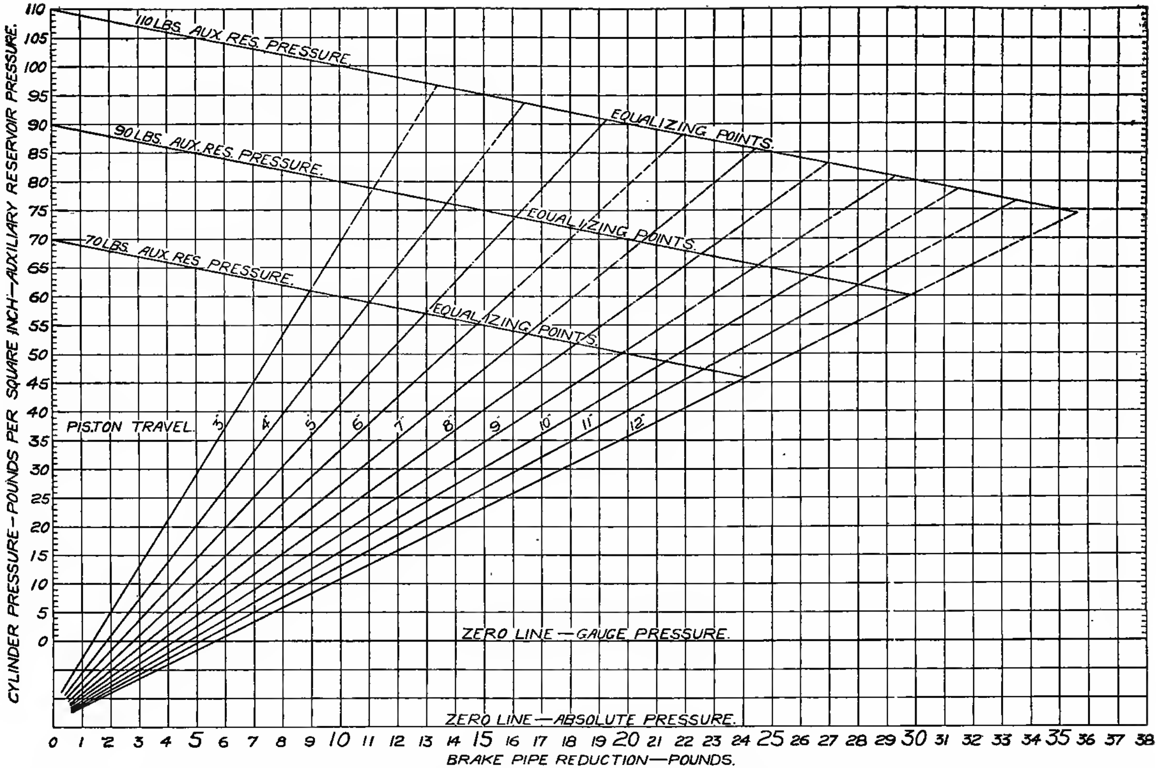


FIG. 19. CHART SHOWING VARIATION IN BRAKE CYLINDER PRESSURE OBTAINED WITH ANY GIVEN BRAKE PIPE REDUCTION OR ON EQUALIZATION FOR VARYING PISTON TRAVEL.

NOTE—Results obtained in practice will be from 2 to 3 lbs. lower than indicated by the chart on account of leakage, etc.

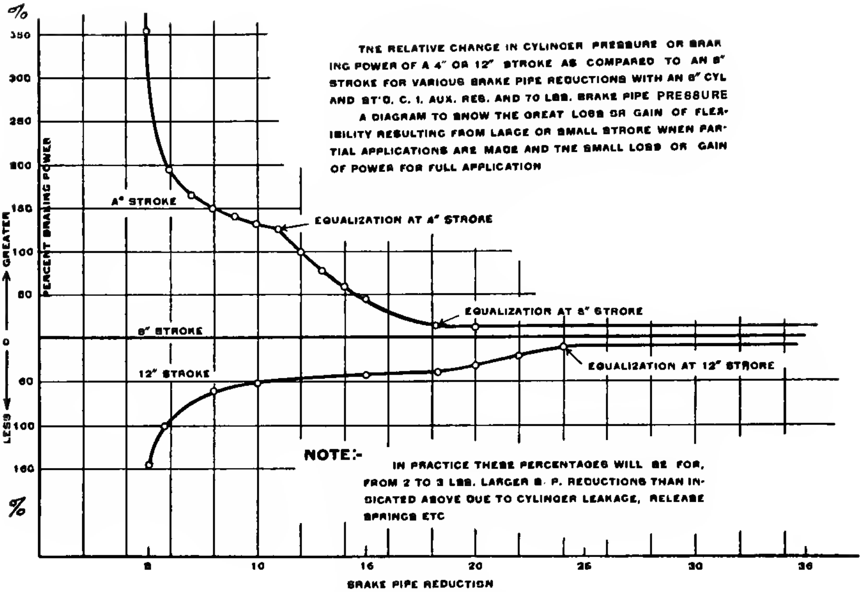


FIG 20. CHART SHOWING EFFECT OF VARIATION FROM STANDARD PISTON TRAVEL ON PERCENTAGE OF BRAKING POWER.

high speed?" At low speeds the stop will be completed before the maximum braking power can be obtained. At medium speeds some of the wheels may slide for a short distance, but as the stop will be much shorter than with a lower braking power, flat wheels will not result. As the speed is reduced during a high speed stop, the natural increase in coefficient of friction due to the decrease in speed is largely offset by the "time and work element" effect on the metals in contact, so that in many cases the coefficient of friction is less at the end of such a stop than at the beginning, owing to the heating of the metals.

Aside from all other considerations, it will be seen that the retarding force would have to be equal to over 16 per cent. of the nominal braking power of 150 per cent. before the wheel adhesion to the rail could be overcome and it is doubtful if any such coefficient of friction is obtained under modern conditions. But you say: "We slide wheels with much less braking power." This, as a general proposition, we do not grant, for it is apparent that a greater retarding force must be obtained than the adhesion of the wheel to the rail to cause wheel sliding and this cannot be obtained from, say, 100 per cent. braking power and the average rail conditions.

What causes wheel sliding is, primarily, unequal braking power which permits of the highest braked vehicles being "jerked or pushed off their feet" by the lower braked vehicles. In addition to this, there is the shift-

ing of weight during a stop, the tendency of the wheels to run up on the shoes, brake hangers having a toggle joint effect and use of flanged brake shoes (which sometimes exert a tremendous leverage), improper piston travel, the effect of which few appreciate (see Figs. 19 and 20), and the mistaken practice often followed of handling the brake valve in such a way that the maximum braking power is developed at the end instead of at the beginning of a stop. Of course, an important factor to be added to the above is the condition of the rail being otherwise than average, which consideration is, and should be, disregarded in a brake design, as there is no possible way to provide for it in advance.

Thus you see. while granting that there is wheel sliding under present conditions, we attribute it to causes other than the braking power employed, and maintain that more wheel sliding will be experienced with a low nominal braking power which will vary in service between wide extremes than where the braking power is nominally high but more uniform. In fact, the proof of what has just been said is continually before you and needs only to be pointed out to be recognized; namely that most wheel sliding takes place with the low braking powers of service applications and not with the high braking powers of emergency applications.

Moreover, with the more recent developments in passenger car brakes, most of the preceding causes of wheel sliding are reduced in a marked degree through the obtaining of the increased flexibility of service operation by return to the proper proportion of auxiliary reservoir to brake cylinder volumes, the quick service feature of the triple valve and quick recharge of the auxiliary reservoirs with the consequent prompt response of the brakes for reapplications and graduated releases and much more efficient retardation caused by proper cylinder pressure for service applications. However, in the last analysis it must also be remembered that there should be no compromise between incidental, individual wheel sliding and safety.

Operation of the Improved Brake for Passenger Cars.

As has been stated, the fundamental principle on which former types of triple valves operated remains unchanged in the new triple valve and only one piece of apparatus, viz., a supplementary reservoir, has been added to the car equipment (see Fig. 21). This is not necessary to the operation of the valve so far as the mere application and release of the brakes is concerned, but adds some important features to it. The additional reservoir is about double the capacity of the ordinary auxiliary reservoir and practically serves the purpose of an unlimited and independent supply of air for performing certain desirable functions. With this source of pressure available, it has been possible to design a triple valve which will accomplish many desirable but hitherto unobtainable results. This new triple valve, called the type "L" triple valve, not only performs all the functions of the former types of triple valves, but adds to them the features of (1), quick service; (2), quick recharge; (3), graduated re-

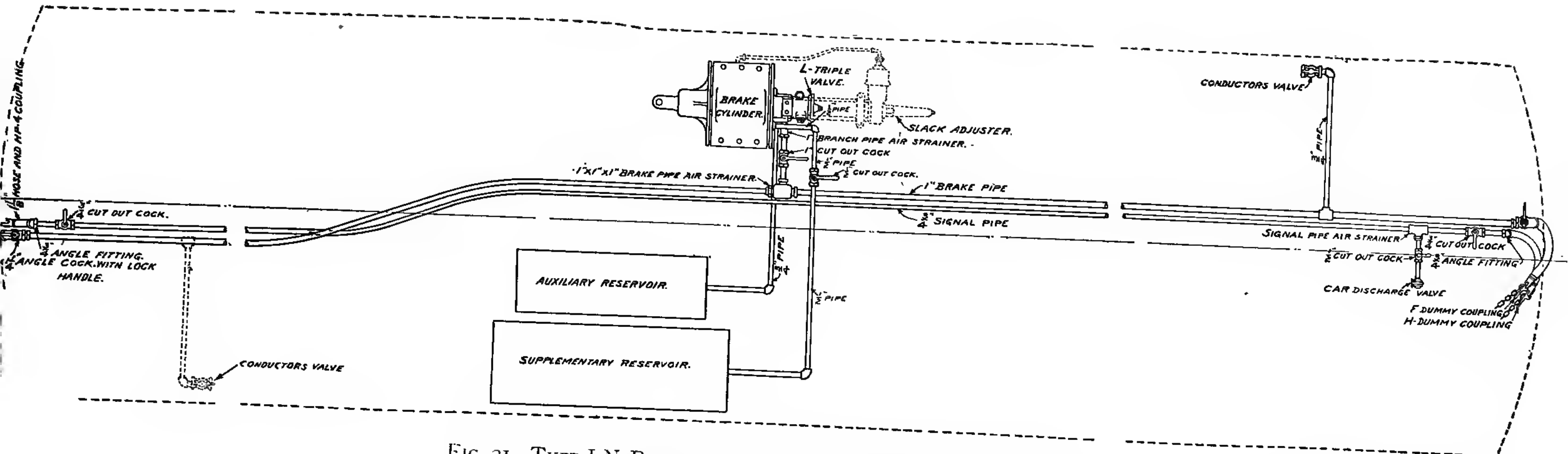


Fig. 21. Type LN Passenger Car Brake Equipment Diagram.

lease; (4), high emergency cylinder pressure, and (5), ability to obtain quick action and emergency cylinder pressure after a considerable service application has been obtained.

In charging, air from the brake pipe enters the auxiliary reservoir through two channels instead of by means of the single feed groove as formerly, there being, in addition to the feed groove, a passage open from the brake pipe past the check valve and through the slide valve to the space above the slide valve and the auxiliary reservoir. As the port leading from above the slide valve to the supplementary reservoir mentioned is also open at this time, both the supplementary and auxiliary reservoirs are charged equally from the brake pipe.

Quick Service Feature.

The brake is applied in service by a reduction in brake pipe pressure, as with former triple valves, but with this difference:—in the movement to service position, the triple valve slide valve and graduating valve (which is also of the slide valve type) make a momentary connection

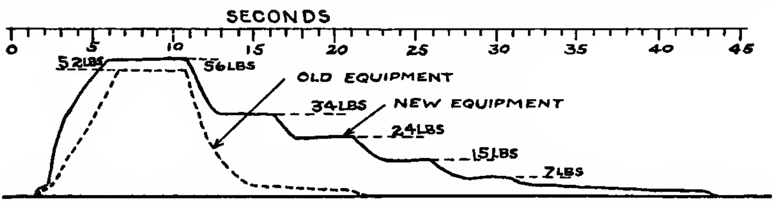


FIG. 22. RACK TEST, 110 LBS. BRAKE PIPE PRESSURE. BRAKE CYLINDER CARDS SHOWING A 20-POUND SERVICE APPLICATION AND TYPICAL RELEASE. OLD AND NEW EQUIPMENTS.

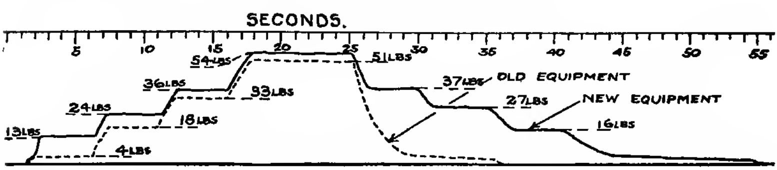


FIG. 23. RACK TEST, 110 LBS. BRAKE PIPE PRESSURE. BRAKE CYLINDER CARDS SHOWING GRADUATED APPLICATION (FROM SUCCESSIVE 5-POUND REDUCTIONS) FOLLOWED BY TYPICAL RELEASE OLD AND NEW EQUIPMENTS.

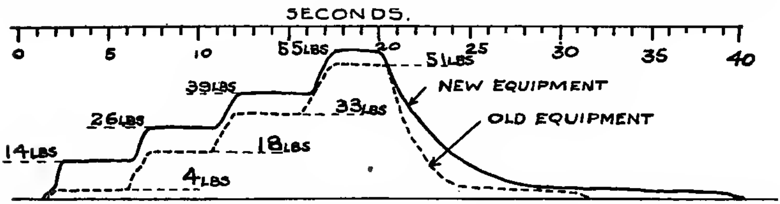


FIG. 24. RACK TEST, 110 LBS. BRAKE PIPE PRESSURE. BRAKE CYLINDER CARDS SHOWING GRADUATED APPLICATION (FROM SUCCESSIVE 5-POUND REDUCTIONS) FOLLOWED BY "STRAIGHT-AWAY RELEASE." OLD AND NEW EQUIPMENTS.

from the brake pipe to the brake cylinder. This connection is closed if the parts move to their full service position, but ordinarily opens and closes with the different brake pipe reductions or graduations of the valves. This constitutes the quick service action of the triple valve in that it causes a slight but definite reduction in brake pipe pressure locally at each valve. The effect of a service reduction in brake pipe pressure at the brake valve is thus quickly and uniformly transmitted from car to car throughout the train in a manner similar to the quick-action operation of a triple valve, but, owing to the relatively small port openings made, correspondingly less in amount, and, as the openings are controlled in unison with and in the same manner as the ordinary service ports, the graduating feature of the brake is unimpaired, and the very serious effect of increase of brake pipe volume largely neutralized.

Thus the influence of this feature is to insure that the brakes apply promptly and become effective quickly and uniformly and thus prevent the surging of the cars due to the slack action and unequal braking power in different parts of the train. When the brake cylinder pressure becomes so high, as from heavy reductions, that to continue such a rapid rise would tend to produce severe strains, the quick service effect automatically disappears.

Fig. 22 illustrates the effect of the quick service feature in its influence on the rate of rise of cylinder pressure on the individual car, when making a heavy service application. As shown by the solid line, the rise of pressure is much more rapid with the new than with the old equipment, there being over 30 lbs. in the brake cylinder with the new equipment when there was only 10 with the old. This would be the more pronounced the longer the train, both with respect to the time required to get the brakes applied and in the rate of rise of cylinder pressure. The quick service feature also has another effect, as shown by Figs. 23 and 24, which contrast a graduated application of the brake in successive reduction of 5 lbs. with both equipments. For the same preliminary reductions it will be seen that about three times as much cylinder pressure is obtained with the new equipment as with the old, which difference, however, becomes less and less as the equalizing point is approached, showing that the effect of the quick service port is felt chiefly in getting the brakes applied and for the low ranges of cylinder pressure, while when the cylinder pressure becomes so high that a rapid rise would be severe, this difference in rate disappears and the pressures rise at about the same rate with both the old and new equipments.

Quick Recharge.

In its movement from release position to service position, the slide valve blanks the port leading from the supplementary reservoir and its pressure therefore remains constant and equal to that normally present in the brake pipe. Consequently, when a release is made in the ordinary way the movement of the slide valve to release position opens communication from the supplementary reservoir to the auxiliary reservoir now

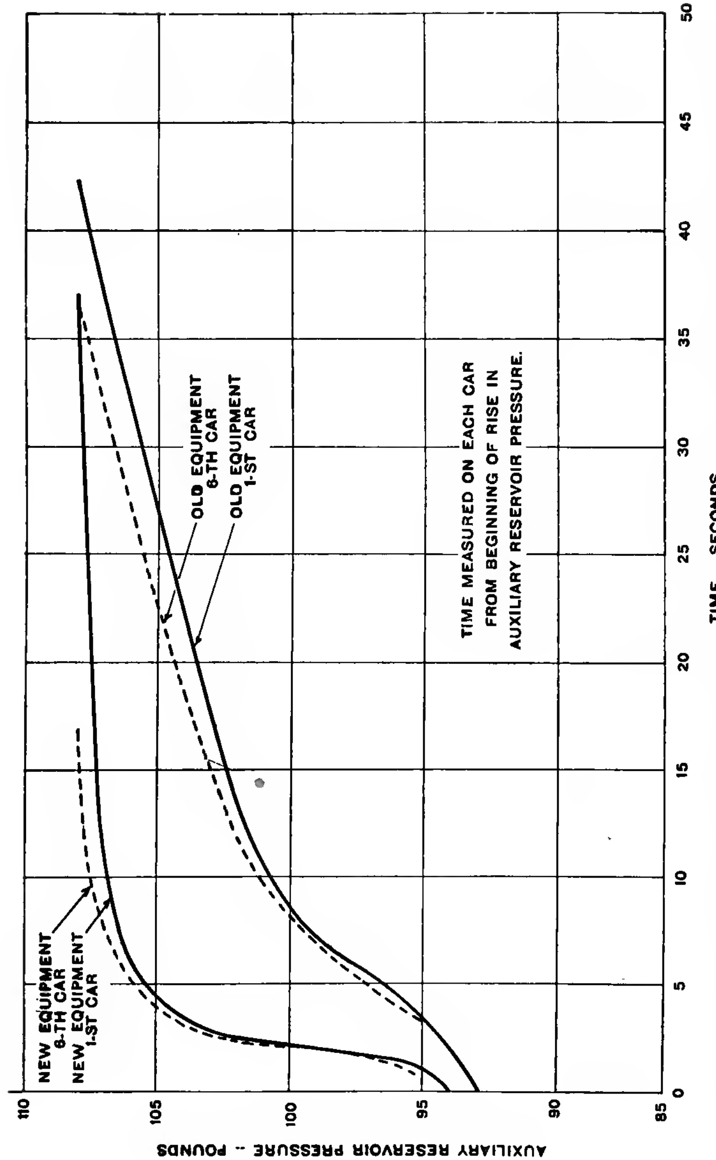


Fig. 25. High Speed Passenger Brake Tests. Standing Train Tests.. Curves Showing Comparative Times Recharging of Auxiliary Reservoir, Old and New Equipment. 110 lbs. Brake Pipe Pressure.

at lower pressure so that the latter is recharged not only through the feed groove and charging port previously mentioned, but also from the supplementary reservoir. This, being of large volume and at practically normal brake pipe pressure, is alone able to almost completely recharge the auxiliary reservoir and in so short a time that the rise in auxiliary reservoir pressure is practically simultaneous with the fall in brake cylinder pressure and the rise in brake pipe pressure. In this way a practical equality of pressure is maintained on the opposite sides of the triple valve piston, which insures that it will respond promptly to a reduction closely following a release and that proper braking power will be secured in response to such successive reductions, with reserve power still sufficient to obtain a higher cylinder pressure on an emergency application than is possible with the old equipment when no previous application has been made.

Fig. 25 illustrates the difference in the recharging of the auxiliary reservoirs with the new and with the old equipments, showing that with the new equipment the increase in reservoir pressure is simultaneous with the rise in brake pipe pressure. These curves were plotted from records taken on the first and sixth cars of a six-car train. After making a 20-lb. service reduction the brake valve handle was placed in full release position for six seconds, then returned to running position.

Comparing the time taken by each equipment to recharge the train to 105 lbs., it is seen that the new equipment required an average of only 4.4 seconds, while with the standard equipment 27 seconds were required, or over six times that required in the former case, which is a saving in time, for the new equipment of 83.7 per cent. This almost instantaneous recharge to 105 lbs. secured with the new equipment is a most desirable feature, as the time lost in waiting for the auxiliary reservoirs to be recharged is practically eliminated, and the ability to make a number of successive applications and releases, with certainty and safety, is secured.

This instantaneous response to successive brake pipe reductions is shown by Fig. 26. The curves show the rise and fall of brake cylinder pressure on four successive 20-lb. reductions from 110 lbs. brake pipe pressure, the fifth rise of cylinder pressure shown being an emergency application following the fourth release. The reductions were made 15 seconds apart. It will be seen that practically the same cylinder pressure was obtained with each service application with the new equipment, while after the first application with the old equipment, 28 lbs. was the highest cylinder pressure obtained. The difference here is due to the fact that with the old equipment the brake pipe was charged up much higher than the auxiliary reservoir, owing to their not having the quick recharge feature. Therefore, at least one-half of the amount of the reduction did no more than draw off the recharge of the brake pipe. It will also be seen that an emergency application with the new equipment resulted in 96 lbs. cylinder pressure being obtained, notwithstanding the very high cylinder pressure resulting from each of the preceding service applications, while with the old equipment the emergency application resulted

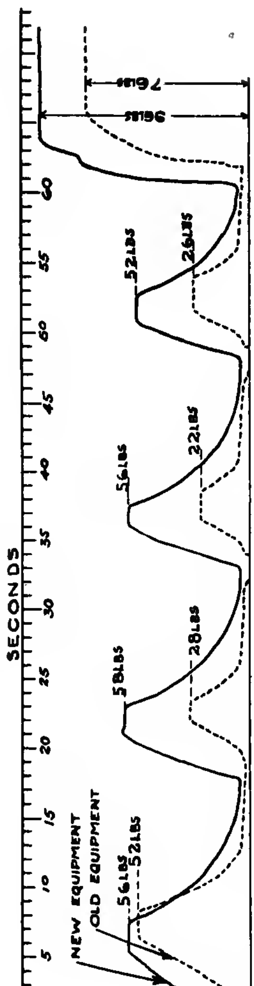


FIG. 26. RACK TEST, 110 LBS. BRAKE PIPE PRESSURE. BRAKE CYLINDER CARDS SHOWING FOUR SUCCESSIVE 20-LB. SERVICE APPLICATIONS AND RELEASES, FOLLOWED BY AN EMERGENCY APPLICATION, OLD AND NEW EQUIPMENTS.

in only 76 lbs. cylinder pressure, or less than 80 per cent. of that obtained with the new, yet this brake had given but low cylinder pressures on the preceding service applications save on the first. If it had been desired to obtain the same cylinder pressure with service applications with the old equipment as was the case with the new, 30-lb. service reductions would have been required instead of 20, in which case the cylinder pressure resulting from the fifth or emergency application would have been very much lower.

Another thing that will be noticed is that, notwithstanding the fact that the brake valve handle was placed in emergency position at the same time in both cases, the cylinder pressure had only *started* to rise with the old equipment by the time that *maximum* cylinder pressure was obtained with the new. This is because with the new equipment the brake pipe and auxiliary reservoir pressures were practically equal at the same time the application was made; consequently, the triple valve piston was in a balanced condition, ready to respond instantly, while with the old equipment the brake pipe pressure was much higher than the auxiliary reservoir pressure, and this difference had to be drawn off before the triple valve could respond. This one illustration shows in a very graphic manner the value of quickly recharging the auxiliary reservoirs and demonstrates that the weakest element in the automatic brake system, namely, the possibility of depleting the auxiliary reservoirs, or failure to recharge them quickly, has been entirely eliminated.

It is interesting to note in passing that the slope of the curve showing the rise of cylinder pressure for the service applications indicates clearly the effect of the quick service feature already referred to. This is particularly noticeable for the first application, when the valves respond at practically the same time.

Graduated Release.

The manner in which the air in the supplementary reservoir is made to assist in recharging the auxiliary reservoir is suggestive and its possibilities evident, for it should not be forgotten that, when releasing, the supplementary reservoir delivers air through the slide valve to the chamber on the *auxiliary reservoir* side of the triple valve piston. Consequently, if the brake pipe pressure is increased sufficiently to move the triple valve piston to release position, but not to equal the equalization pressure of the supplementary and auxiliary reservoirs, the flow of air from the former to the latter will increase the pressure on the auxiliary reservoir side of the piston above that in the brake pipe on the opposite side. This will cause the piston to again start to service position (an increase in auxiliary reservoir above brake pipe pressure having the same effect as a decrease in brake pipe pressure below auxiliary reservoir pressure) and in its movement cut off the ports supplying air from the brake pipe and supplementary reservoir to the auxiliary reservoir and close the exhaust port from the brake cylinder, thus permitting only a partial release of the brakes. This operation can be repeated, each successive increment in brake pipe pressure being accompanied by a corre-

sponding increase in auxiliary reservoir pressure and partial release or "graduation" of brake cylinder pressure until the supplementary and auxiliary reservoir pressure become equal, after which the triple valve piston will remain in release position and permit the final recharging of the supplementary and auxiliary reservoirs together.

Fig. 22 not only shows the effect of the quick service feature, as before mentioned, but shows also the possibility of graduating the brakes off with the new equipment as contrasted with the uncontrollable release of the old equipment. Here four graduations of the release were made before the final release, which demonstrates that at last the long desired ability to graduate the release of the brakes, as was possible with the straight air or vacuum brake, is now a practical feature of the much more efficient automatic brake. This diagram also illustrates that it is now possible to apply the brake with one application as strongly as may be necessary for the stop and yet graduate it off as the stopping place is approached, thus making the stop in the shortest possible time consistent with smoothness and accuracy. As shown by Fig. 23 it is not necessary to apply the brake fully with one reduction if circumstances require otherwise; neither is it necessary to graduate the release with the new equipment if a straight away release happens to serve the purpose better (see Fig. 24), as, for instance, when letting the brakes off after they have been applied to steady the train around a curve, etc. Only an approach to the graduated release could be obtained with the old equipment, viz., by using what is termed the "two-application method" of stopping, which, however, consumes valuable time, depletes the auxiliary reservoir at a time when most likely to be needed and, unless done expertly, is often more prolific of shocks than is the method of applying the brakes step by step and releasing just as the train stops.

Figs. 26, 22, 23 and 24, when considered together, graphically illustrate the difference in the service application feature of the new and old equipments and show that all the features of the old equipment have been obtained and improved and certain new and essential features added.

High Emergency Pressure.

Having in reserve the air in the supplementary reservoir, it is but logical that it should be utilized in conjunction with that in the auxiliary reservoir and brake pipe to augment the brake cylinder pressure in emergency applications when, as we have seen, the braking power available should be considerable higher than the maximum permissible in service. This is accomplished by means of a "by-pass" valve incorporated in the triple valve structure and remaining inert except during a quick-action application of the brakes. The movement of the triple valve slide valve to emergency position, however, causes the "by-pass" valve to operate so as to open communication from the supplementary reservoir direct to the auxiliary reservoir, which is, in turn, open to the brake cylinder, so that for emergency applications the ordinary service auxiliary reservoir is, in effect, replaced by a reservoir three times as great and the emergency cylinder pressure correspondingly increased.

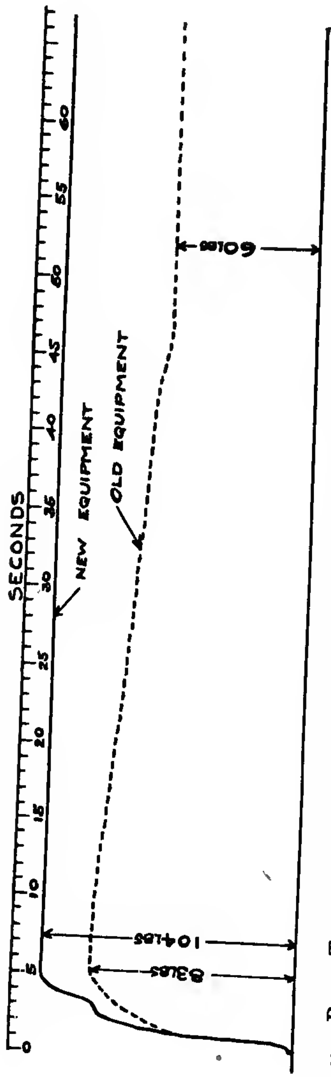


FIG. 27. RACK TEST. 110 LBS. BRAKE PIPE PRESSURE, BRAKE CYLINDER CARDS. EMERGENCY APPLICATION. OLD AND NEW EQUIPMENTS.

During service applications the brake cylinder is connected through ports in the slide valve with a safety valve of large capacity attached to the body of the triple valve. This safety valve, therefore, serves the same purpose as a high speed reducing valve during service applications, viz., it prevents the brake cylinder pressure rising above that which is predetermined by the setting of the safety valve as being the maximum permissible in service applications with the proper margin of safety against wheel sliding. When an emergency application is made, however, all connection to the safety valve is cut off and the high emergency cylinder pressure is maintained without reduction until a release is made.

Fig. 27 illustrates the high pressure emergency and retaining feature of the new equipment as compared with the action of the old equipment, 110 lbs. brake pipe pressure being carried in each case. It will be seen that with the old equipment 83 lbs. was the maximum obtained, as against 104 lbs. with the new equipment, and that this latter was obtained in the cylinders of the new equipment before the 83 lbs. was reached with the old equipment, and, finally, that the pressure in the case of the old equipment was gradually reduced so that, at the end of 45 seconds, only 60 lbs. remained in the cylinders while 104 lbs. still remained in the brake cylinders of the new equipment. This shows an accomplishment remarkable in two respects—1st, 21 lbs. higher brake cylinder pressure should be obtained in the one case without any increase of initial pressure carried; and 2nd, that by the combination of the high pressure and its retention during the stop an effective means is provided to compensate for the lowered coefficient of friction between the brake shoes and wheels, resulting from the increased work required at each brake shoe under modern conditions.

Quick Action and High Emergency Pressure After Service Application.

The supply of compressed air reserved in the supplementary reservoir during service applications is utilized to increase the service brake cylinder pressure already obtained, should there suddenly be need for stopping as short as possible during the progress of an ordinary service stop. This is accomplished in the design of the triple valve alone, without additional apparatus, and materially increases the efficiency of the new equipment over former types as regards safety of operation. The cases in which it is necessary to have a high emergency pressure at command, after having made a service reduction, are obvious. For example, while making a slow-down, for signal, station stop, or otherwise, a sudden stop may become necessary either in response to a signal or to avert disaster. Furthermore, with the present conditions of frequency and high speed suburban train service and the necessity for making station stops in the shortest possible time, which requires the making of full service applications, it is imperative that the train be equipped with a brake which will permit of emergency applications being obtained after as considerable

a service application. With the new equipment an emergency application may be made immediately, whether a release has been made or not, with a certainty of securing a high brake cylinder pressure in either case.

Fig. 28 illustrates this feature, which has added very materially to the safety resources of the brake, in that it is now possible not only to vent the reserve supply of air in the supplementary reservoir at full pressure into the brake cylinder after a service application, but also to

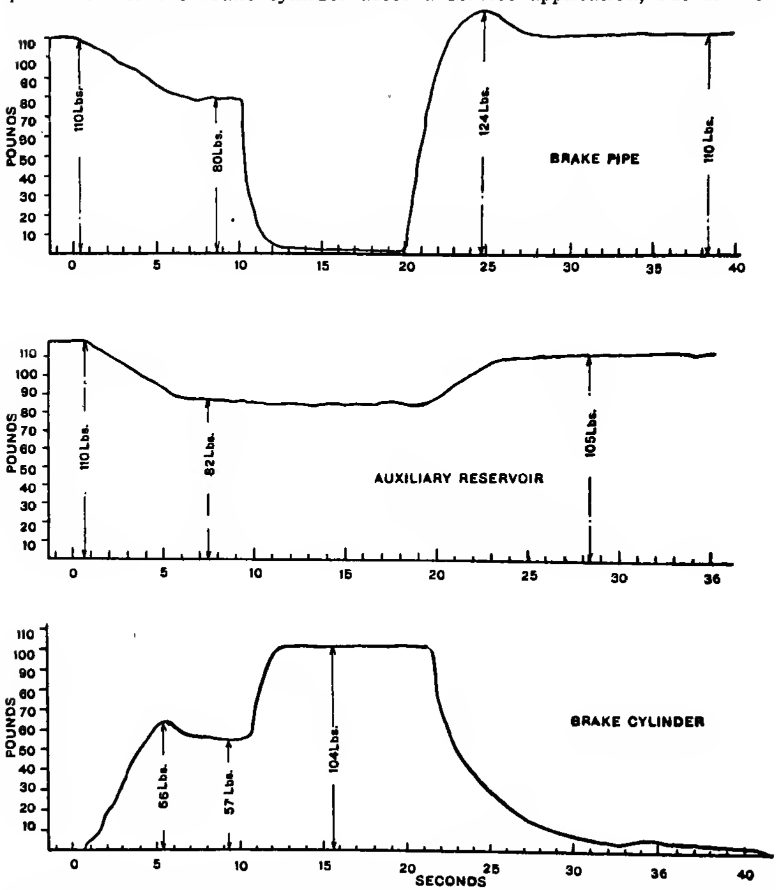


FIG. 28. RACK TEST, 110 LBS. BRAKE PIPE PRESSURE. COMPARATIVE BRAKE CYLINDER BRAKE PIPE AND AUXILIARY RESERVOIR CARDS. 30-LB SERVICE REDUCTION FOLLOWED BY EMERGENCY. NEW EQUIPMENT.

transmit quick action throughout the train under these conditions and in as short a time as if a quick action application had been made at the beginning. From Fig. 28 it will be seen that after about a 30-lb. reduction had been made, giving a cylinder pressure of over 60 lbs. that an emergency

application was then made and not only over 100 lbs. cylinder pressure obtained but also that quick action was transmitted, as seen from the difference in rate of fall in brake pipe pressure just before and just after the emergency application was made.

As will be seen, the three diagrams of Fig. 28 illustrate graphically the relations of pressures and the movement of air in the brake pipe, auxiliary reservoir and brake cylinder, respectively, during the progress of the application and release. With this before you, we feel justified in saying that never before has the personal equation been reduced to such low terms or the potentiality of a given quantity of compressed air so completely and so effectively utilized.

Service Results.

The curves which follow will illustrate the effect of the operative features which have been described and the results thereby secured with regard to train control in actual service.

The cards chosen as representative of results in actual service are taken from two different demonstrations, viz., that made at Absecon in 1907 on the Pennsylvania Railroad and at Hayward, California, by the Southern Pacific Railroad in 1908. Sufficient information is given on each cut itself to make extended interpretation unnecessary; therefore, only the salient differences in operation and results will be mentioned.

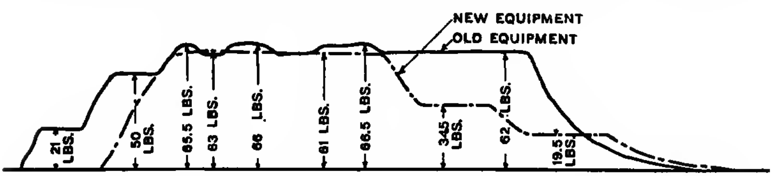


Fig. 29. High Speed Passenger Brake Tests. Standing Tests. Brake Cylinder Diagrams from First Car, Showing Method of Making Service Applications and Releasing with Old and New Equipments.

Fig. 29 shows the difference in the service application and release feature of the two brakes in actual train operation. It will be seen that the brake with the old equipment is graduated on, but the release was without control at the instant of stop, while with the new brake the application was commenced much later, was made with one reduction and graduated off, insuring a smooth and accurate stop, and yet the train stopped at the same place as with the old equipment.

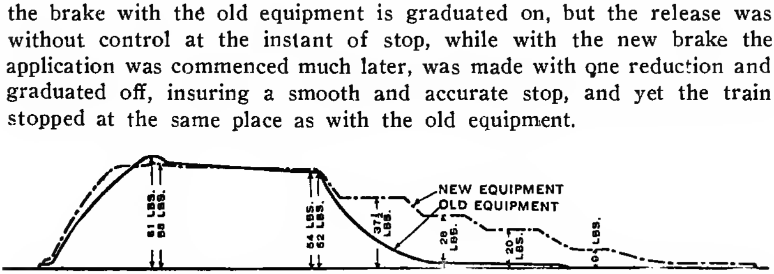


Fig. 30. High Speed Passenger Brake Tests. Standing Tests. Comparative Diagrams from 7th Car Showing Control of Brake Cylinder Pressure by Engineer During Release of Brakes with Old and New Equipment.

Fig. 30 shows that quick-service feature in the application and also again the difference in the release of the brakes.

Fig. 31 is a characteristic card of an emergency application with the two equipments, 90 lbs. being used as the standard brake pipe pressure with the new equipment and 110 lbs. with the old. It will be seen that even with this difference carried a higher cylinder pressure was obtained with the new equipment than with the old, and because of the retaining feature the average cylinder pressure with the *new equipment* for the stop was much higher than with the old equipment. This, of course, makes clear the reason why a shorter stop can be made using 90 lbs. brake pipe pressure with the new equipment than can be made with the old equipment using 110 lbs. brake pipe pressure.

In Fig. 32 we have curves showing comparative stops with the new and old equipments from a speed of 84.2 m. p. h., and as these curves were made for the cars alone, the engine having been cut off at the point of brake application in each run, it will be seen that they are strictly comparable as to the relative efficiency of the two equipments.

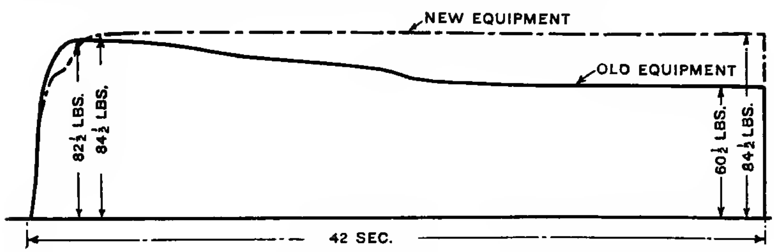


FIG. 31. HIGH SPEED PASSENGER BRAKE TESTS. EMERGENCY APPLICATIONS, STANDING TESTS. COMPARATIVE DIAGRAMS OF CYLINDER PRESSURE ON 1ST CAR USING 90 LBS. BRAKE PIPE PRESSURE WITH NEW EQUIPMENT, 110 LBS. BRAKE PIPE PRESSURE WITH OLD EQUIPMENT.

The great distance required to make the stop will, no doubt, impress most of you—particularly those who have been thinking of about 1,000 feet as being the distance in which a high speed train should be stopped. Here we see that about 2,600 feet is required in which to make the stop, and had the engine been attached to the cars the distance would have been much greater. But we need only to call your attention to the initial speed (84.2 m. p. h.) and the great amount of work required per second from the brake shoes to stop in the distance shown, in connection with what has been said before when considering the theoretical side of this question, particularly with reference to those factors which affect the coefficient of friction between the shoes and the wheels, to suggest the cause.

The difference in stop in favor of the new equipment was 319 feet. The speed at which the train with the old equipment was running when it passed the point at which the train with the new equipment stopped was 30 m. p. h.

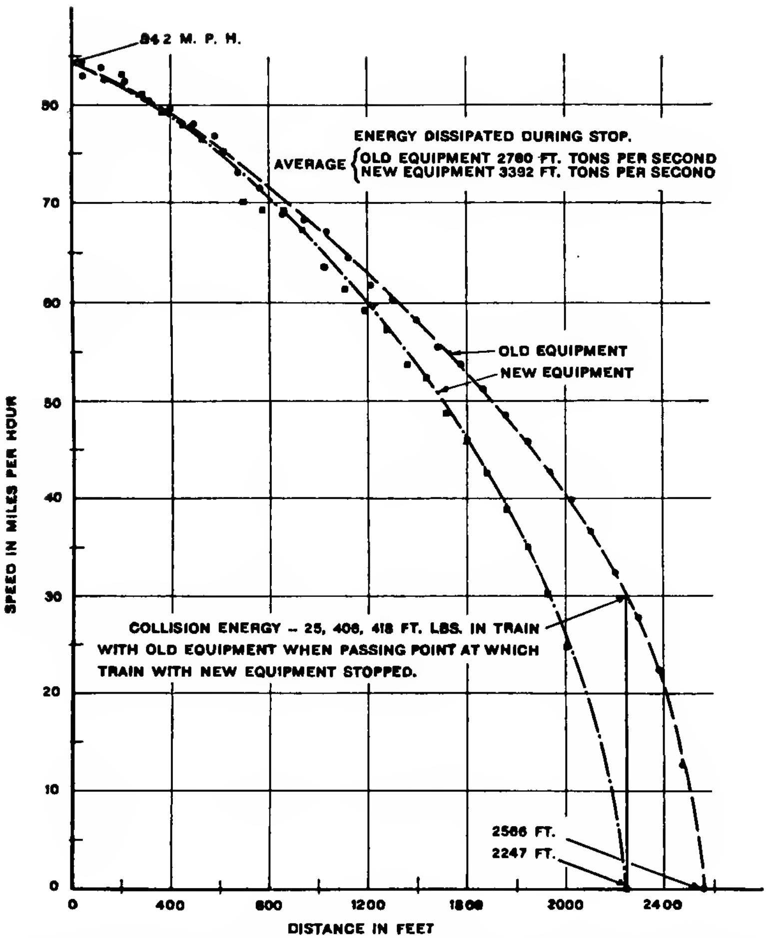


FIG. 32. HIGH SPEED PASSENGER BRAKE TESTS. EMERGENCY APPLICATIONS. RETARDATION CURVES FOR CARS ALONE IN BREAK-AWAY TESTS. 10 CARS, 110 LBS. BRAKE PIPE PRESSURE.

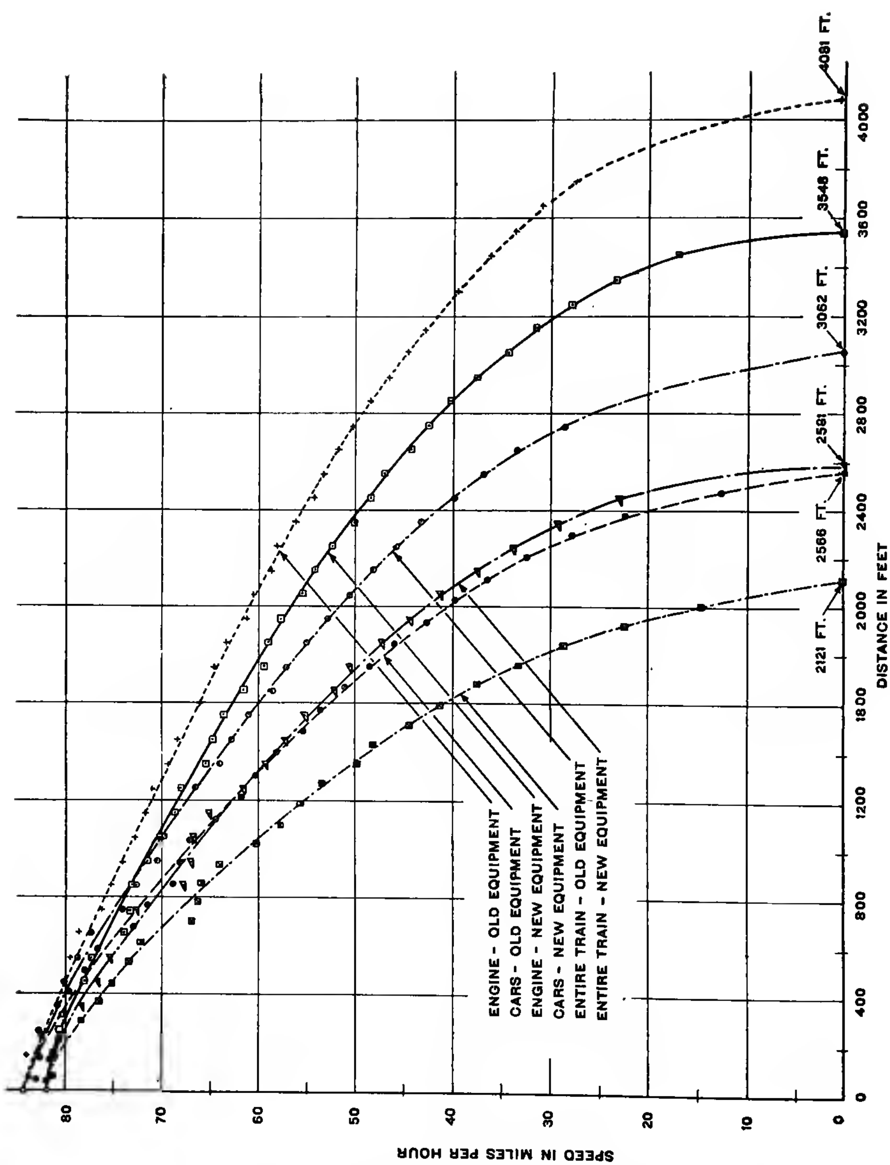


FIG. 33. HIGH SPEED PASSENGER BRAKE TESTS. EMERGENCY APPLICATION AND RETARDATION CURVES FOR TWO ENGINES ALONE AND 10 CARS ALONE IN BREAK-AWAY TESTS, AND FOR ENTIRE TRAIN OF TWO ENGINES AND 10 CARS. 110 LBS. BRAKE PIPE PRESSURE.

The collision energy in the train with the old equipment at this time was 25,400,000 foot lbs. The best measurement of the real effectiveness of the two brakes, however, is shown by a comparison of the foot tons of work performed by each per second, that of the old equipment being 2,780 and of the new, 3,392 foot tons per second, or 612 foot tons more work per second for the new equipment, representing a gain of about 22 per cent. in stopping power.

The effect of the engine referred to above is graphically illustrated in Fig. 33, which shows stop curves for the engines alone and for the cars alone, as well as the train complete. This chart is given chiefly that those interested may be able to appreciate the detrimental effect of so much "unbraked" weight of the locomotive; that is to say, its relatively low per cent. of braking power.

It will be seen by comparing the stops of the train equipped with the old equipment that the stop was about 500 feet longer (3,062 feet) with the engine attached than when it was detached. Furthermore, the cars with the old equipment, when detached from the engine, stopped in 2,566 feet while the engines ran 4,081 feet, or 1,515 feet farther. As the brake pipe pressure carried was the same on both engine and cars, it will be seen that this difference in stopping distance must have been due to failure to utilize the braking power possible for such pressures on the locomotive to the same degree as on the cars.

Fig. 34. Break-Away Tests, Showing Gap Between Locomotive and First Car After Coming to a Stop. (See Fig. 33)

In other words, the efficiency of the car brakes for the same pressure carried was much greater than that of the locomotive. A similar comparison for the train with the new equipment is obvious.

However, a circumstance much more impressive is that from nearly the same speed the extreme differences in the stops of these vehicles was from 2,121 feet to 4,081 feet, or a gap of 1,960 feet and that one, which ran the farthest, had a speed of about 60 m. p. h. when it passed the point at which that which ran the shortest distance stopped. Surely there is not only room for, but need of, improvement somewhere when such a condition exists.

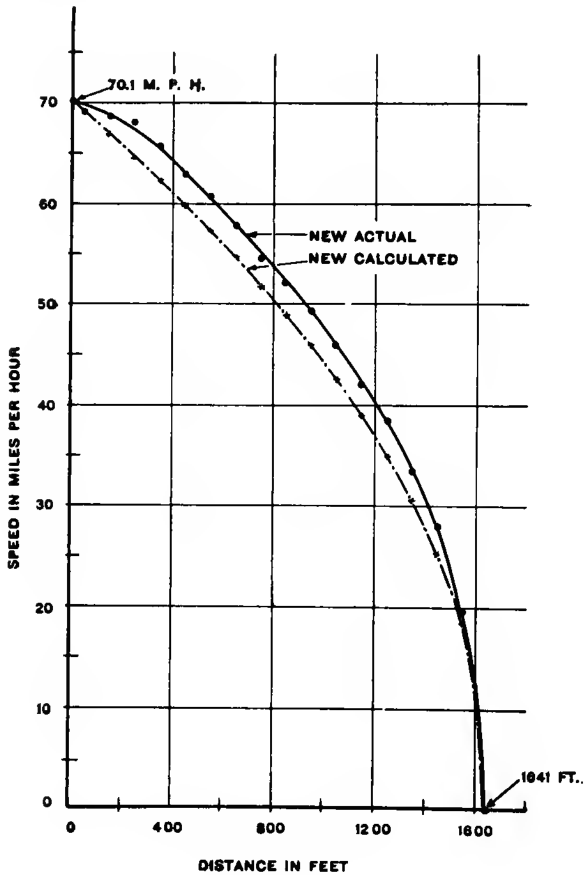


FIG. 35. HIGH SPEED PASSENGER BRAKE TESTS. EMERGENCY APPLICATIONS. COMPARISON OF ACTUAL RETARDATION AND THAT WHICH WOULD HAVE OCCURED IF ACTUAL AVERAGE COEFFICIENT OF FRICTION HAD BEEN CONTINUOUS THROUGHOUT THE TEST.

Fig. 34 shows the gap between engines and cars in one of the foregoing runs and may serve to give some idea of how an eye witness is impressed by a demonstration of this kind. One is led to wonder where a modern train would stop without the air brake.

Fig. 35 consists of curves plotted from records of stops during the same series of demonstrations as the preceding, for the purpose of analyzing the variations in the coefficient of friction between the shoes and the wheels during the stop. It will be seen that the coefficient of friction was nearly constant throughout the stop, the tendency to increase as the speed reduced being offset by the time element and the resultant effects involved. To illustrate further, it may be pointed out that the coefficient of friction at the initial speed and pressure should, theoretically be about 9½ per cent., while at a speed of 5 m. p. h. the coefficient of friction should be about 27½ per cent., whereas the average coefficient actually realized for the entire stop was about 9 per cent. and the close agreement between the actual and calculated curves shows that there was little variation for this.

It is of interest to note in passing that in order to reduce the speed of a train a certain amount, the energy to be destroyed varies directly as the average speed. For instance, in order to reduce the speed of a train from 70 to 60 m. p. h., 13 times as much energy must be destroved as is necessary to decrease the speed of the same train from 10 to 0 m. p. h., the average speed in the first case being 65 m. p. h., and in the second 5 m. p. h., the former being 13 times the latter.

Fig. 36 represents comparative service stops with new and old equipments. With the new equipment the brake was applied heavily at the commencement of the stop and graduated off as the end was approached, and the inclination of the retardation curve shows that the great retardation incident to slow speed was eliminated, yet the stop was made about 75 feet shorter than with the old equipment, where, in order to obtain a comparatively smooth and accurate stop, the initial application had to be released and a second made. The cylinder pressure diagrams show how this was accomplished.

Fig. 37 is a similar diagram for an emergency stop from a speed of about 77 m. p. h. for each equipment, the comparison being particularly noteworthy from the fact that while 110 lbs. brake pipe pressure was used with the old equipment only 90 lbs. brake pipe pressure was used with the new equipment, other things being as equal as possible, yet the stop with the new equipment was made in 150 feet shorter distance than with the old equipment. The reason for this will be apparent from an inspection of the cylinder pressure cards on this diagram, which show that notwithstanding the 20 lbs. lower brake pipe pressure employed the brake cylinder pressure with the new equipment was much higher than with the old.

What the difference in stop would be when equal brake pipe pressures are employed with both equipments is shown on Fig. 32, for 110 lbs. brake pipe pressure, and on Fig. 38 for 90 lbs. pressure. The latter shows

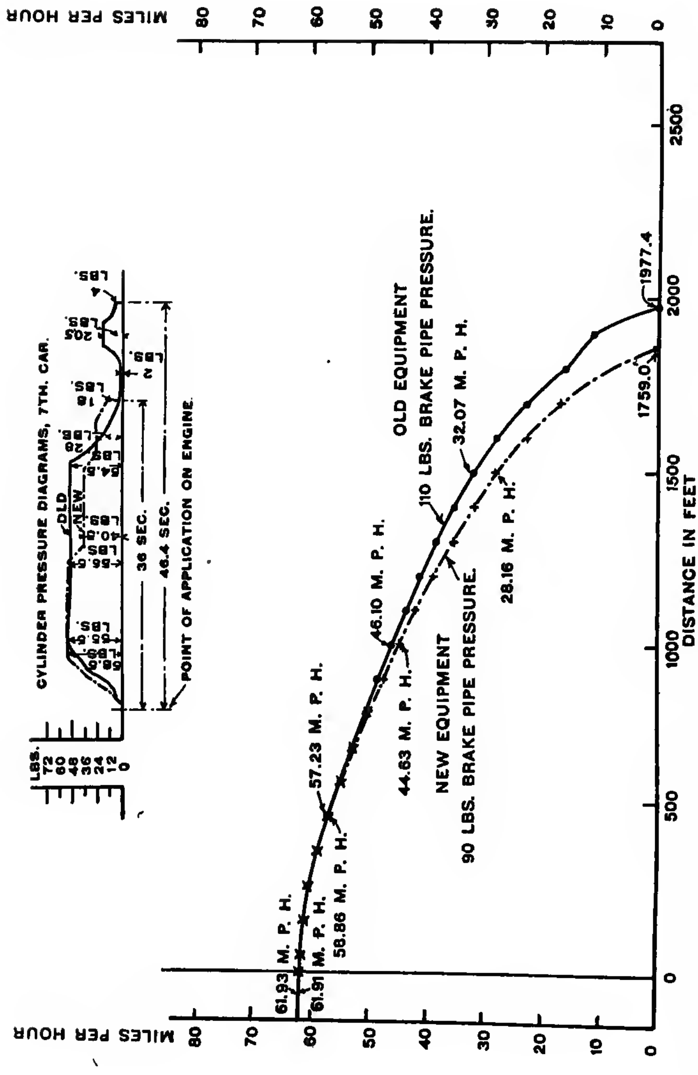


FIG. 36. HIGH SPEED PASSENGER BRAKE TESTS. SERVICE APPLICATIONS. COMPARATIVE RETARDATION CURVES FOR 8-CAR TRAIN, 110 LBS. BRAKE PIPE PRESSURE WITH OLD EQUIPMENT, 90 LBS. BRAKE PIPE PRESSURE WITH NEW EQUIPMENT.

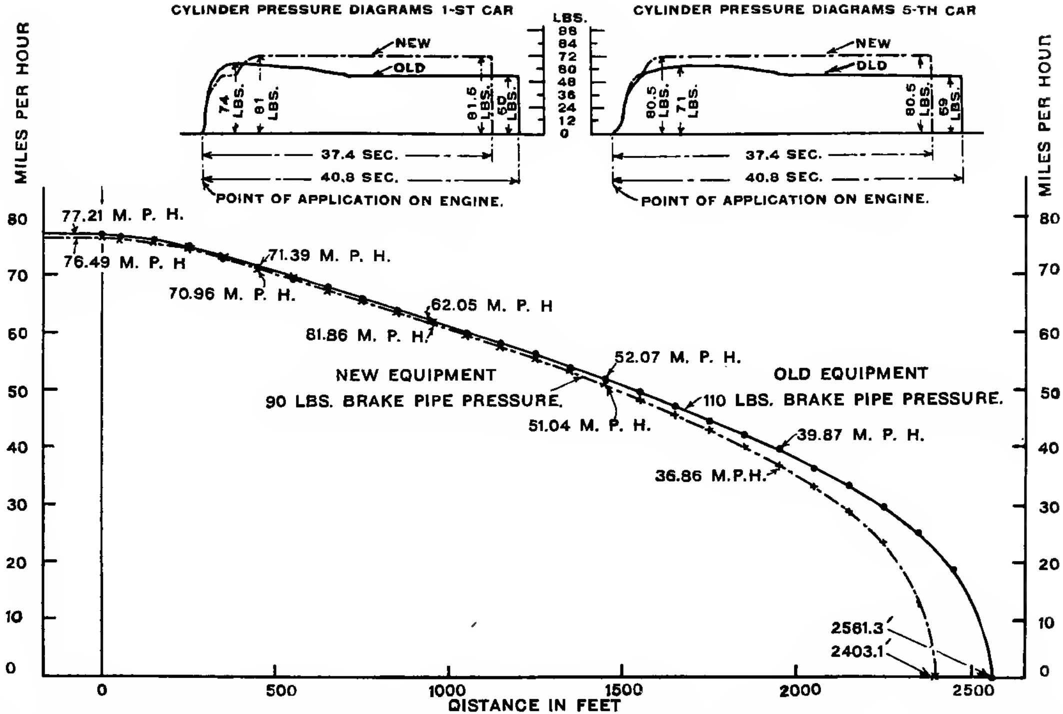


FIG. 37. HIGH SPEED PASSENGER BRAKE TESTS. EMERGENCY APPLICATIONS. COMPARATIVE RETARDATION CURVES FOR 5-CAR TRAIN, 110 LBS. BRAKE PIPE PRESSURE WITH OLD EQUIPMENT, 90 LBS. BRAKE PIPE PRESSURE WITH NEW EQUIPMENT.

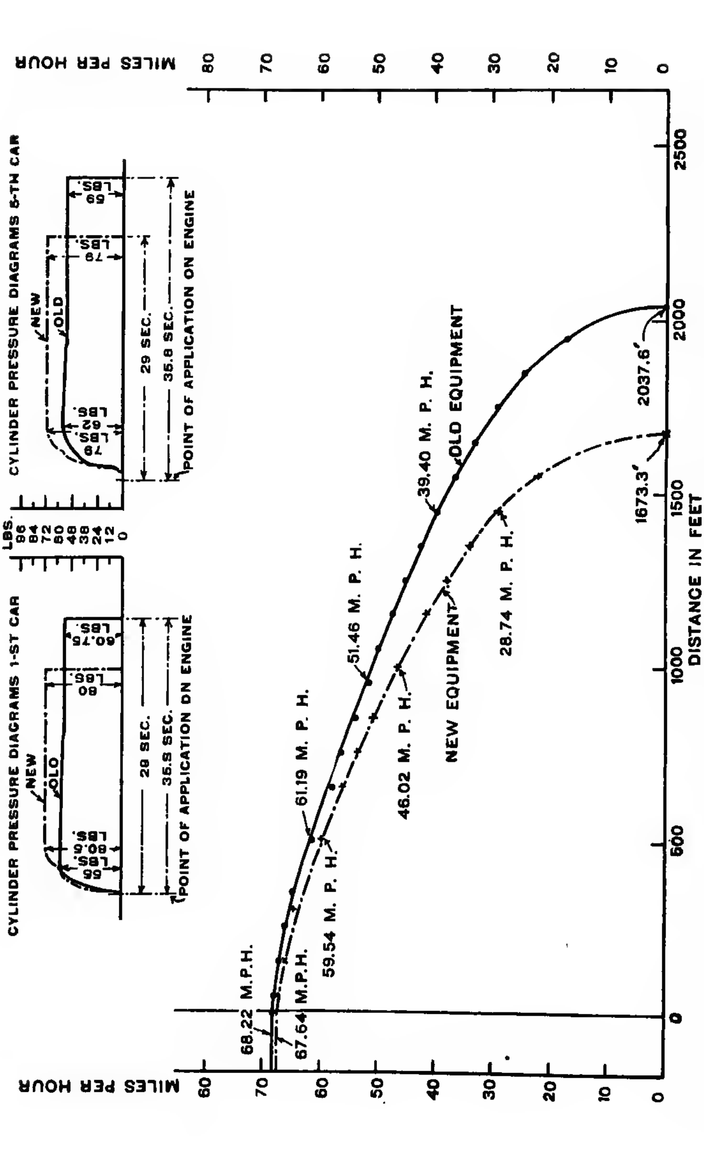


FIG. 38. HIGH SPEED PASSENGER BRAKE TESTS. EMERGENCY APPLICATIONS. COMPARATIVE RETARDATION CURVES FOR 8-CAR TRAIN, 90 LBS. BRAKE PIPE PRESSURE.

that with equal brake pipe pressure from an initial speed of about 68 m. p. h., the train was stopped 364 feet shorter with the new than with the old equipment, the reason for this difference again being evident from the cylinder pressure cards at the top of the diagram.

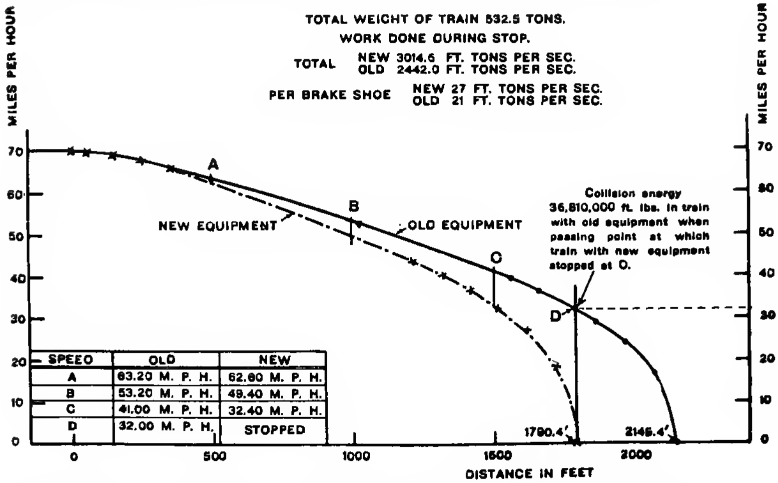


Fig. 39. High Speed Passenger Brake Tests. Emergency Applications. Comparative Retardation Curves for 8-Car Train, 90 lbs. Brake Pipe Pressure.

Fig. 39 shows the retardation curves of Fig. 38 reduced to the same initial speed and plotted on a distance base.

It will be evident from this stop, 1st, that the pressure carried was 90 lbs. with each equipment; 2nd, that the stop is much longer than is ordinarily supposed to be required for a modern train; 3rd, that the difference in the stops in favor of the new equipment was 355 feet; 4th, that when the train equipped with the old brake passed the point at which the train with the new equipment stopped its speed had only been reduced to about one-half the initial speed, viz., 32 m. p. h.; 5th, that at this time there was stored upon it a "wrecking" energy of about 36,000,000 foot pounds; 6th. that it passed the point at which the new stopped about 7½ seconds before the train with the new equipment reached the point; 7th, that it was still running at over 20 m. p. h. when the train with the new equipment was stopped; 8th, that it ran for about 100 feet after the other train had stopped; 9th, that at the time the new was stopped the old had a "wrecking" energy of over 14,000,000 foot pounds, and finally, 10th, that the total work done in foot tons per second was 3,014.5 with the new and 2,442 with the old.

Fig. 40 is very important from the fact that it illustrates the speed-time relations existing throughout the stop as Fig. 39 does the speed-distance relations for the same stop, and offers further illustration and proof of what was said with reference to Fig. 35., viz., that with the mod-

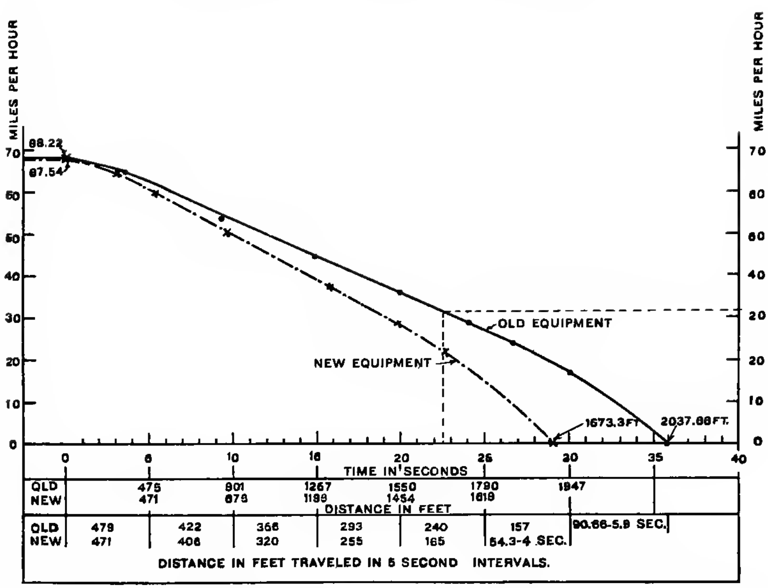


FIG. 40. HIGH SPEED PASSENGER BRAKE TESTS. EMERGENCY APPLICATIONS. COMPARATIVE SPEED TIME RETARDATION CURVES FOR 8-CAR TRAIN, 90 LBS. BRAKE PIPE PRESSURE.

ern equipment the coefficient docs not vary materially during the stop. This is shown by the close approach of each of the curves of Fig. 40 to the theoretical straight line which would result from an absolutely uniform coefficient of friction throughout the stop.

In these last two diagrams are found all the reasons why braking power must be greatly increased as the speed and pressure on the brake shoe is increased, if we are to obtain the same proportionate retarding force as formerly.

One other phase of the question needs to be considered which, no doubt, has occurred to many of you, viz., what is going to be the effect of such a high nominal braking power as we have been considering and which, in many cases, is now being put into practice.

While probably most of you have reached the conclusion that the effect at very slow speeds will hardly be distinguished, as the train will be brought to a stop before the maximum braking power is obtained and that at medium speeds the result will be to perhaps somewhat shorten the stop, for obviously the elements of time and speed cannot in such cases affect the result through altering the coefficient of friction materially, to demonstrate that such results as these would actually obtain, tests were made at very low speeds, of which Fig. 41 is an example. While the initial speed of the train with the new equipment was somewhat higher than that of the other, the curves are practically parallel throughout the

stop, showing that the retarding forces actually realized during the stops (which lasted only 11 seconds in one case and 10.8 seconds in the other) were approximately equal throughout.

At lower speeds the same effect is observed. Records of an emergency stop made from 20.6 m. p. h. with the new equipment show that the train was brought to rest in a distance of 143 feet in 7.4 seconds time.

These two slow speed stops are representative, as a great many have been made with very high braking power during the several series of tests that have been made during the development of the new high speed brake

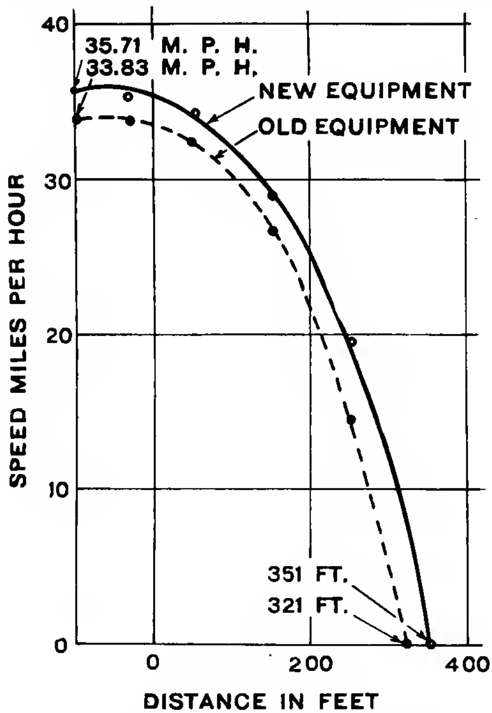


FIG. 41. HIGH SPEED PASSENGER BRAKE TESTS. EMERGENCY APPLICATIONS. COMPARATIVE RETARDATION CURVES FOR STOPS AT LOW SPEEDS. 110 LBS. BRAKE PIPE PRESSURE. OLD AND NEW EQUIPMENT.

equipment. The chief object of these tests at slow speed was to determine what wheel sliding would take place, but in no case at slow speeds did any wheel sliding occur and it is a remarkable fact that not in any of these series of tests has a single wheel been removed for flattening.

To consider for a moment the means which have enabled us to shorten so materially the stopping distance for emergency applications at high speeds and yet preserve the flexibility of service operation requisite for the proper handling of the train under ordinary conditions we see

from Fig. 42 that for the same brake pipe pressure (70 lbs.) carried, the braking power obtained with the old equipment for a 10-lb. reduction is 40 per cent., while with the new it is only 32 per cent. and on a full service application with the old equipment 80 per cent. is obtained and 90 per cent. with the new. This shows conclusively that smoothness in handling has been much improved, while at the same time greater stopping power, even for service, is obtained when the speed warrants or it is necessary. In emergency it will be seen that the braking power with the old equipment is 84 per cent., while with the new equipment 118 per cent. is realized.

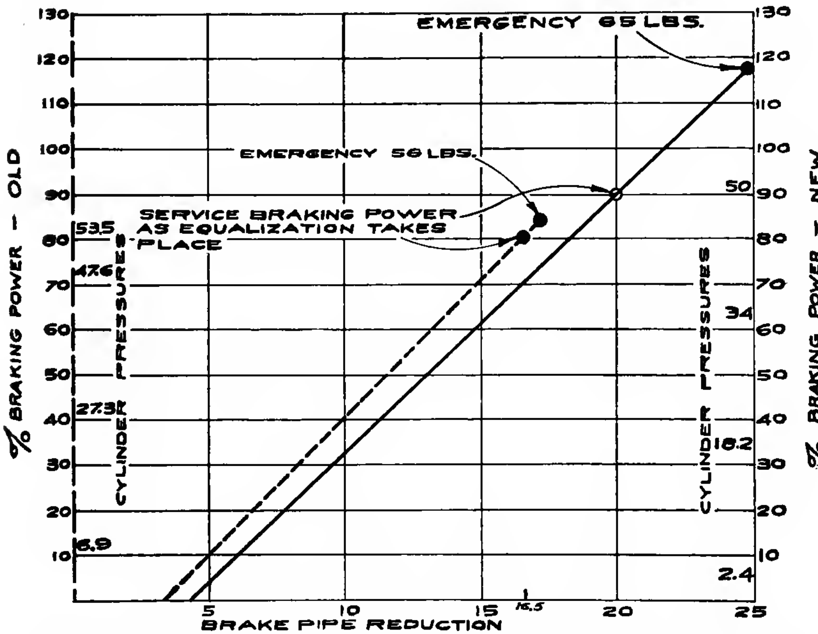


FIG. 42. CHART SHOWING CYLINDER PRESSURE AND BRAKING POWER OBTAINED WITH OLD AND NEW EQUIPMENTS, USING 70 LBS. BRAKE PIPE PRESSURE.

Fig. 43 further illustrates the principles involved by contrasting the new brake at 70 lbs. with the old at 110 lbs. brake pipe pressure and while the service results are the same as pointed out, with the exception that 60 lbs. cylinder pressure or 70 per cent. braking power is now obtained with the old equipment for a full service reduction, the emergency braking power is now increased to 127 per cent. with the old equipment, or 9 per cent. more than for the new equipment at the lower brake pipe pressure. When it is considered, however, that the high speed-reducing valve reduces this pressure while the stop is being made with the old equipment it will be seen that the average stopping power of the new equipment

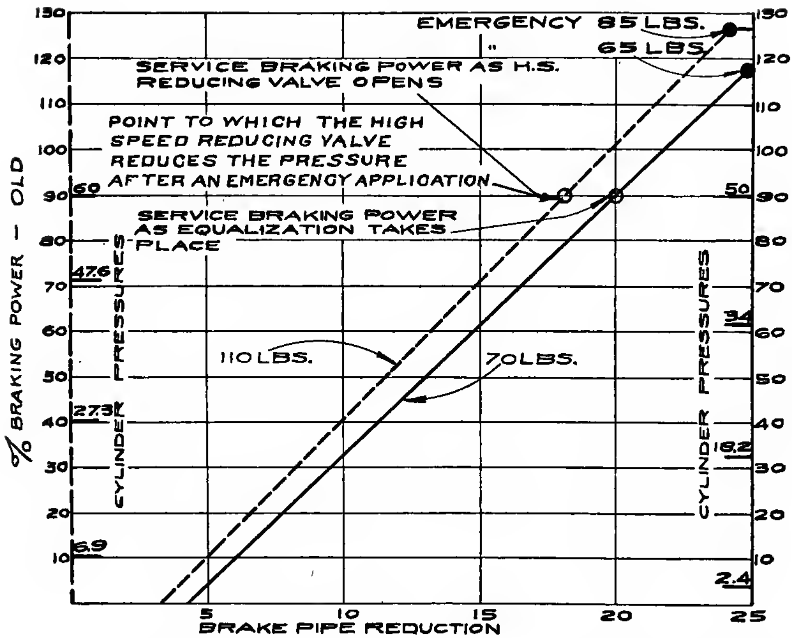


FIG. 43. CHART SHOWING CYLINDER PRESSURE AND BRAKING POWER OBTAINED WITH OLD EQUIPMENT USING 110 LBS. (DOTTED LINE) AND NEW EQUIPMENT USING 70 LBS. (FULL LINE) BRAKE PIPE PRESSURE.

is greater, using only 70 lbs., than that of the old equipment using 110 lbs. brake pipe pressure. If 110 lbs. pressure were employed in both cases the braking power with the old equipment would average about 108 per cent., while with the new equipment 190 per cent. would be obtained and maintained throughout the stop. From this we may appreciate, as in no other way the advantages and great possibilities of using a small reservoir volume for service applications and a large reservoir volume for emergency applications.

As showing concretely the relative efficiency of the various forms of brakes for passenger trains, we present for your consideration Fig. 44 showing approximately the reduction of distance required in which to stop a given train of one locomotive and six cars from a speed of 60 m. p. h., since the introduction of the air brake. If the page be inverted so that Fig. 44 is viewed up-side down, we will have a fair idea of what the stops would have been through the respective periods of train development had there been no change in the air brake since first applied.

Fig. 45 further illustrates the tendency of modern rolling stock to lower brake efficiency. The retardation curves show the stopping distance from about the same initial speed of a train composed of cars weighing 30,000 lbs. and braking at 83 per cent. and a train of 84,000

lbs. cars braking at 150 per cent. It will be seen that notwithstanding the 60 per cent. greater braking power of the heavier train, the differerce in stop is not greatly in its favor. The reason for this is clear when we consider that the work done during the stop for the light train was 14½ foot tons per brake shoe per second while with the heavy train it was 29

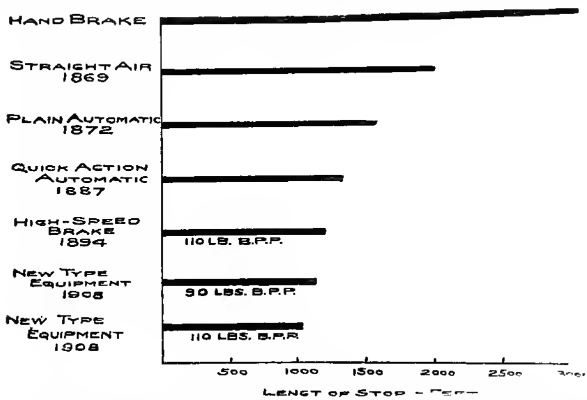


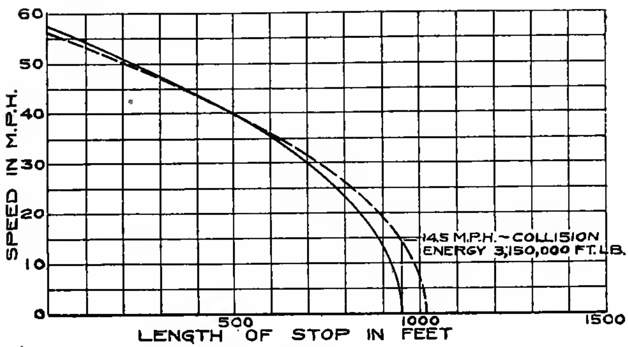
FIG. 44. CHART SHOWING PROGRESS OF AIR BRAKE EFFICIENCY AS INDICATED BY COMPARATIVE DISTANCES IN WHICH TRAIN OF LOCOMOTIVE AND SIX CARS HAS BEEN STOPPED FROM A SPEED OF 60 M. P. H. FOR VARIOUS TYPES OF EQUIPMENT.

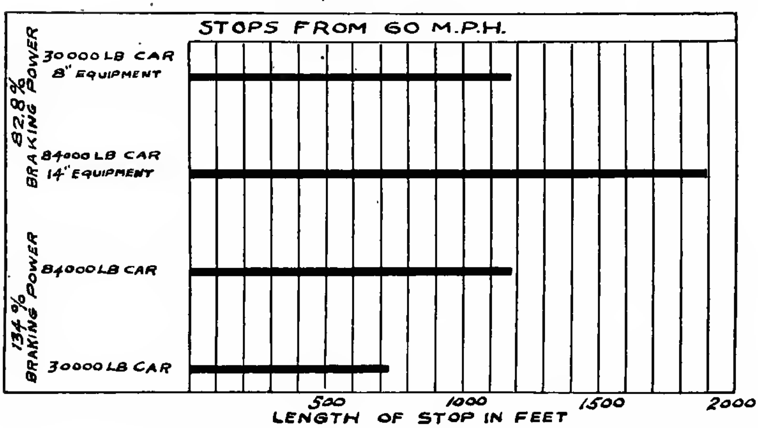
foot tons per brake shoe per second, which shows that under modern conditions each brake shoe is doing about twice the amount of work required of the old equipment in order to make approximately the same stop, which consequently lowered the coefficient of friction and thus tended to equalize the actual retarding forces developed in the two cases.

The curves in Fig. 45 show, 1st, the length of stop for the light train with the equipment of its day; 2nd, what the stop would have been with the heavier train had there been no change in brake equipment to correspond to the increased weight of train; 3rd, what braking power was actually required to stop the heavy train in the distance the light train was stopped with its brake equipment; and 4th, what the stop of the light train would be if it were possible to apply to it the brake equipment required for the heavy train. We believe we can leave this as a significant and all-sufficient example of what is required to meet modern conditions as effectively as they were provided for in the past.

Summary.

From what has gone before it will be seen that the existence and development of the passenger brake devices which have been described have come about, not spontaneously, of themselves, or solely for themselves, but in response to a definite need or for the purpose of accomplishing certain necessary and desired results, the end in view always be-





Date	Speed in M. P. H.	Length of Stop in feet	Time of Stop in Sec.	Weight of Trains tons	Work in ft. tons performed by brakes			B. P. %
					Total	Per Sec.	Per Brake Shoe Per Second	
1875	56.0	1020	22.	227	23900	1086.4	14.7	82.8
1907	57.3	954	18.7	559	61300	3278	28.75	150.

Dotted curve shows stop on Midland Railway, 1875, with the Westinghouse Automatic Brake.

Full-line curve shows stop made on W. J. and S. R. R., 1907, with the Westinghouse "LN" Brake.

Had the braking power, as shown in the last column of the table and represented by the full-line curve, been 134 per cent. instead of 150 per cent., the two stops would have been the same.

FIG. 45. COMPARATIVE RETARDATION CURVES AND BRAKING POWER CHART FOR TRAINS OF 1875 AND 1907.

ing the safeguarding of life and property and increasing the facility, economy, and dispatch with which larger volumes of traffic can be handled.

Briefly, the conditions to be overcome and the objects to be attained may be summarized as follows:

Conditions.

Increased weights of trains, greatly decreasing the relative efficiency of the brake and increasing the energy to be overcome in bringing the train to a standstill. Of two trains on the same number of wheels having the same nominal percentage of braking power, one being twice the weight of the other, the heavier train will run at least one-third farther than the other.

Higher running speeds, increasing the energy to be overcome in making the stop in proportion to the *square* of the speed and adding directly to the length of stop according to the time required to obtain effective braking power on the train as a whole.

Greater frequency of trains, which increases the necessity for stopping quickly in a rapidly increasing ratio. Not only is it of more importance than ever that the trains be readily controlled within the distances between signals, but, with double or four track roads, there is the added greater possibility of the track on which the train is running being blocked by a break-in-two or other accident on the opposite track.

Increasing insistence upon the comfort and convenience of passengers and at the same time for greater economy in the handling of traffic, the latter being, in the nature of things, antagonistic to the former, without some special provision is made, looking to ultimate rather than circumstantial economy.

Object of Improvements.

In Service Applications: 1st, Much more flexible control of the train, greatly reducing possibility for shocks. 2nd, More uniform braking power, reducing surging in trains and flat wheels. 3rd, Shorter, smoother and more accurate stops. 4th, Constantly recharged auxiliary reservoirs which increases the safety to the highest degree. 5th, Better protection against excessive braking power in service applications.

In Emergency Applications: 1st, The human factor in the question is reduced to a low point. 2nd, The increased percentage of braking power and prompt rise of brake cylinder pressure compensates in a large degree for the decrease of the retarding force due to the increased work the brake shoe now has to perform as compared with the old style brake. 3rd, Trains can be stopped in somewhere near the same distance as when the cars were lighter. 4th, *Emergency pressure is available even after a service application has been made to an extent never before attained.*

An example of what is to be gained in stopping power is shown by the following:

An eight-car train weighing 500 tons can be stopped from a speed of 70 m. p. h. in 355 feet shorter distance using the new "LN" equipment in place of the old standard high speed "PM," all other conditions of brake pipe pressure, leverage, etc., being the same; *i. e.*, the "PM" brake train will run 20 per cent. farther than the "LN" and pass the point at which the "LN" train stopped at a speed of 32 m. p. h., having at that moment a collision energy of 35,810,000 foot pounds. Furthermore, the "PM" train would reach the point at which the "LN" train stopped four seconds earlier, thereby giving that much less time to clear the obstructions or close the draw-bridge, for example.

An example of decreased efficiency of the brakes on a modern train as compared with a train of 1875 is shown by the following:

In that year a passenger train braked at 82 per cent. was stopped from the speed of 56 m. p. h. in 1,000 feet. In 1907, a train braking at 150 per cent. and running at 57.3 m. p. h. was stopped in 954 feet, showing that about 70 per cent. more braking power had to be used to stop in approximately the same distance, the difference being only in weight of the train.

And here we may be pardoned for pointing out a remarkable feature in connection with these improvements, viz., that an increase of 65 per cent. in braking power over that of the present high speed brake is obtainable, without any increase in the pressure carried; thus the first cost is the only increased expense involved, whereas with all previous improvements in brake apparatus the gain has not only involved additional first cost but also greatly increased cost of operation and maintenance.

From what is herein set forth it will be seen that the statement so often made, viz., that the brake, as allowed to exist on most roads, is good enough for practical purposes, is evidence that on this subject, as well as others, there are those whose convictions are in perfect accord with their understanding—and both are wrong. Every start must be followed by a stop, generally as a part of the regular schedule; sometimes to avoid accident. Stopping is important in both cases, for in the schedule stops, economy of time is just as important as in acceleration, while in emergency, to stop is of vital importance. The reason why the stopping of trains does not receive the consideration it warrants must be because—1st, its value and importance are not understood; 2nd, the rate of deceleration is so much greater than that of acceleration that the efficiency of the brake compared to what it might be is not appreciated; or, 3rd, greater faith in Providence than in a brake.

The Freight Car Brake Equipment.

As the brake for many years was practically the same for passenger and freight cars and as these were treated together to that part of the paper where they became different for passenger cars, it will be sufficient to state that for quite a long time after the first changes were made for passenger cars there was no change in the freight car brake. It was soon apparent, however, that changes would have to be made if the brakes on freight cars were to maintain their value and position as a part of the transportation equipment.

This was partly because the increased ratio of the capacity of cars to light weight (upon which the braking power is necessarily based), was materially reducing the braking power when the cars loaded, as compared with those where the capacity and light weight were not so wide apart. In addition, there were many causes arising which prevented the brakes applying as certainly and as effectively as before, notably larger feed grooves and longer trains. These had the effect of making the reduction of brake pipe pressure so slow that, while a reduction of pressure was of course obtained, it would often be insufficient to produce the differential between the auxiliary reservoir and brake pipe pressure that is necessary to move the triple valve parts. Moreover, if the parts did move, since the

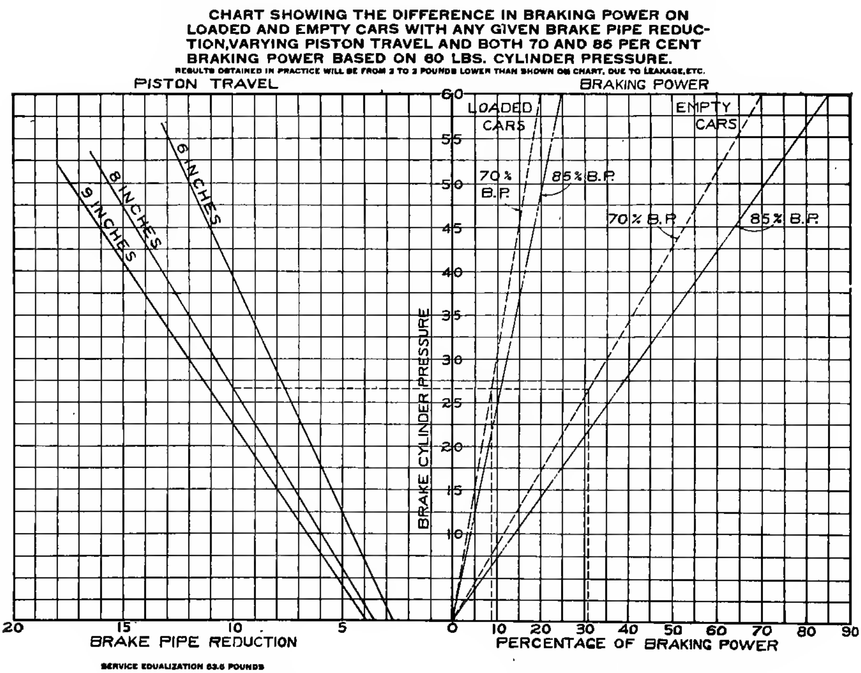


FIG. 46. EFFECT OF VARIATION IN PISTON TRAVEL.

air could flow from the auxiliary reservoir to the brake cylinder at any greater rate than the brake pressure is falling, it often passed out of the leakage groove of the brake cylinder, or did not accumulate sufficiently to expand the packing leather and the brake did not apply. As this condition was contributed to by bad condition of the valves and cylinders, it led to a higher standard of repairs, and, on the whole, fairly satisfactory results were obtained. Some, however, in the effort to obtain sufficient braking power on the loaded cars, increased the braking power by raising the leverage ratio, and by shortening the piston travel. Both

these methods are wrong, as they help the load but little, but seriously widened the difference of braking power between the load and empty, thus producing severe shocks, etc. The reason for this will be evident on an inspection of Fig. 46.

The only way to obtain the desired train control with the then existing brake apparatus, without introducing detrimental features, was to increase the brake pipe pressure carried, which, obviously, did not change the percentage of braking power per pound of cylinder pressure, nor increase the tendency to "break-in-two" by increasing the difference of braking power between the loaded and empty cars, but did give an increase of power for heavier reductions and affected all cars alike.

This increase of pressure, however, simply increased the possible braking power and reserve, but did little toward insuring the application of the brakes on medium or light service reductions, or reducing the time element, and did not help the release at all.

It will be noted in passing that this plan was adopted when it was found necessary to increase the braking power on passenger cars. It is far more important that this method be followed with freight cars, because of the difference in the braking power when light and loaded cars are hauled in the same train.

Features of Improved Brake for Freight Cars.

Two ways were open to obtain the desired results. One was to improve the apparatus by the introduction of new features so as to get the efficiency of operation with long and heavy trains that had previously been obtained with short trains. This was the more reasonable, because, when the triple valve was invented, it was thought that if it operated satisfactorily on trains of 50 cars of the class then used, that this was as much as it would be called upon to do. The other, which also involves the first, was to devise an "empty and loaded" car brake, that the loaded car might be properly braked and greater uniformity of braking power on all cars thus secured. This is important, seeing that, next to safety, uniformity of retardation on all cars is the most desirable feature of a brake. The first of these two means of betterment is exemplified in what is known as the quick-service (type K) triple valve, which will be described in what follows.

The improvement would undoubtedly have come much earlier had it not been that, generally speaking, only part air trains were operated (the number of cars coupled up being, say, 50 per cent. of the number composing the train); therefore, if the engineer used reasonable care and judgment in bunching the slack before applying the brakes all went well. When, however, the trains became "all air"—that is, all the brakes were coupled up and the trains long—the problems of certainty of brake application, uniform release, and uniform recharge presented themselves with added force, and it became imperative that they be solved.

Quick Service.

The service outlet at the brake valve was already as large as permissible; in fact it was large enough to let all the air out about as fast as the friction of the pipes would let it come from the rear. Hence, to have enlarged this outlet would have increased the likelihood of producing undesired quick action and would have certainly brought about a quicker and heavier application of the brakes at the forward part of the train than at the rear, with consequent running in of the slack, resulting in shocks and danger of breaking-in-two on the recoil. For these reasons it was useless to endeavor to obtain the desired results here. This was all the more manifest, because the same difficulties were there being encountered that had previously made necessary the quick-action feature of the triple valve. The solution, therefore, was to find means of adding a serial yet graduating service feature to the triple valve. This was found more difficult than anything yet attempted with the triple valve, and it was only after many trials and failures, each, however, teaching us something, that it was accomplished. After it was perfected, it was put in service for about two years before being made commercial, since which it has more than fulfilled expectations. This new feature is called a *quick-service feature,* and assists in making brake applications certain and *uniformly* effective on long trains by creating a difference of pressure between that of the brake pipe and auxiliary reservoir, locally, on each vehicle when a reduction is first started at the brake valve; thus all brakes apply and the application runs through the train fast enough to very materially reduce shocks.

It will be seen that with these valves every one helps the other to apply, and, therefore, none fail. With the old type this action was the other way about, for if one failed, it made it more difficult for another to apply, and so on, because it increased the brake pipe volume to be reduced by adding the auxiliary reservoirs of the failing valves to it. Not only do the new valves assist each other in applying, but when mixed with the old types in trains, they assist these also, so that the action when both devices are mixed promiscuously in a train is almost equal to that when they are all of the later type. By this means the application of the brakes is made as certain, as rapid, and free from shocks on a 50-car train as it was formerly on a 30-car train without the quick service feature.

Uniform Release.

Another consideration was the release of the brake—always an operation calling for skill and judgment, but now beyond this because of the time element due to length of train.

Just as the pressure in the brake pipe falls more rapidly at the head end of the train, as has been explained, so conversely, the rise of the brake pipe pressure when a release is made is more rapid at the front than at the rear end because of its proximity to the source of supply and the natural frictional resistance to the flow of the air.

To compensate for this, the *uniform release feature* was added to the triple valve in order that the release of the rear end of the train might take place as rapidly as that of the forward end of the train. It is well known that in releasing with the old standard type of brakes, those at the forward end of the train commence to release first—in fact, the brakes at the head end are entirely released before those near the rear end commence to release. Therefore the slack runs out, resulting in severe shocks and perhaps breaking the train in two. With the release at the head end retarded, *i. e.*, taking place slower than with the old valve a simultaneous or uniform release on the train as a whole is brought about; thus the slack cannot run out and shocks and break-in-twos are avoided as much as with the shorter and lighter trains of the past.

Uniform Recharge.

The third new function added to the valve for freight cars was that of *uniform recharge*. This was added to bring about a more uniform recharging of the brakes throughout the train. With the old type of valve, the recharge at the head end was much more rapid than at the rear because

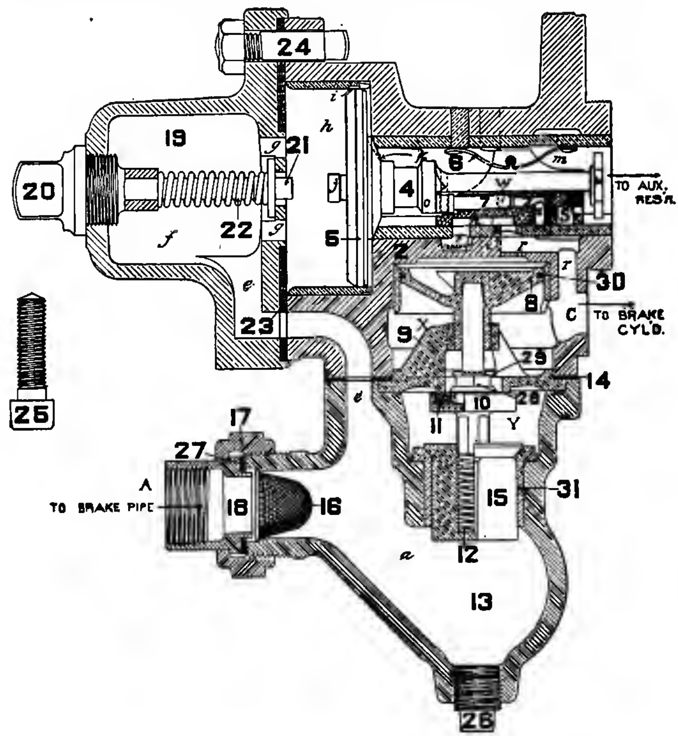


FIG. 47. THE TYPE H, QUICK-ACTION FREIGHT TRIPLE VALVE. (OLD STANDARD.)

of the high pressure at the head end when the brakes were being released. This alone brought about a re-application of the brakes when the handle was returned to running position, and was largely responsible for what is known as "stuck brakes." Uniform recharge lessens this objectionable feature to a marked degree, and, in addition, when a re-application is made by the engineer shortly after release, the brakes apply much more uniformly and certainly throughout the train than is the case when the auxiliary reservoirs are charged much higher at the front than towards the rear of the train. It should be understood, however, that this uniform recharge applies to the train as a whole, and compensates for the higher pressure at the head end by permitting the charging ports at the rear end to remain of uniform size while decreasing those where the pressure is the highest; thus, after such a release, each brake will operate when an application is made, and effective braking power will be developed on all cars.

Operation of the Improved Brake for Freight Cars.

All the foregoing statements relative to the desirability of adding to the operative functions of the old standard quick action triple valve might

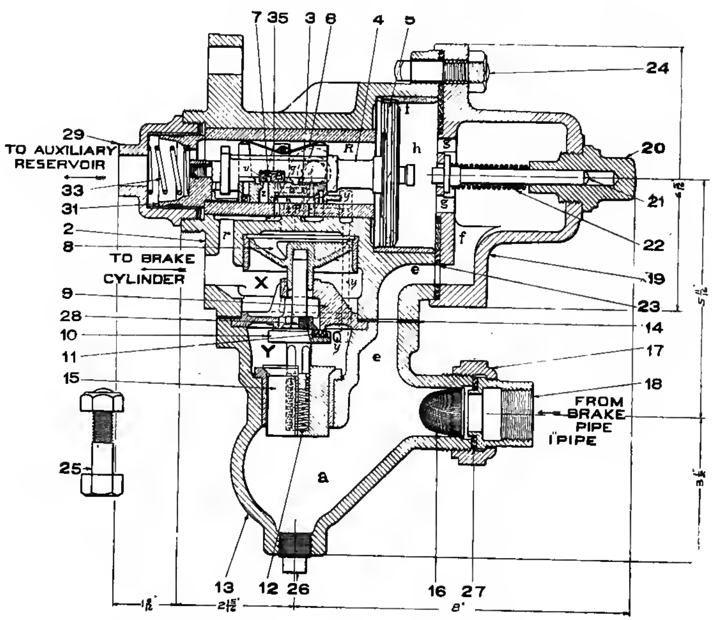


FIG. 48. THE TYPE K, QUICK-ACTION, QUICK-SERVICE, UNIFORM RELEASE, UNIFORM RECHARGE FREIGHT TRIPLE VALVE. (NEW STANDARD.)

be accepted as true and still the sufficient objection raised that to accomplish such results would require apparatus too cumbersome, complicated, or delicate, to be practicable. In passenger service, refinement of apparatus is not, *per se*, looked upon with the suspicion or positive intolerance which it encounters when considered with reference to freight equipment. But if the desired purpose can be accomplished without adding to the delicacy or complexity of the apparatus beyond a certain practicable limit, the end justifies the means. In the case of the new freight triple valve (Type "K," Fig. 48) this principle has been a prime consideration, as will be appreciated when it is stated that the desirable features of operation mentioned above have been secured by slightly altering the porting of the old standard triple slide valve and adding to the auxiliary reservoir end of the triple valve the equivalent of a second graduating stem and spring, and so slight are the further changes that the old type of valves can easily be converted into the new.

No attempt will be made to explain the operation of valve in detail, as this is fully covered in instruction pamphlets which are available upon request.

Quick Service Feature.

The brake is applied in service by a reduction in brake pipe pressure, as with former triple valves, but with this difference. In the movement to service position the triple valve slide valve and graduating valve (which is also of the slide valve type) make a momentary connection from the brake pipe to the brake cylinder which is closed if the parts move to their

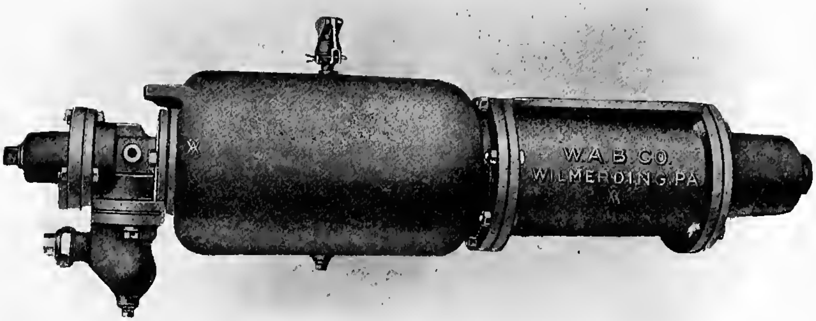


Fig. 49. Standard Combined Freight Brake Equipment. Type K Triple Valve, Auxiliary Reservoir, and Brake Cylinder.

full service position, but ordinarily opens and closes with the different brake pipe reductions or graduations of the valves. This constitutes the quick service action of the triple valve, in that it causes a slight but definite reduction in brake pipe pressure, locally, at each valve. The effect of a reduction in brake pipe pressure at the brake valve is thus quickly and uniformly transmitted from car to car throughout the train in a manner similar to the quick action operation of a triple valve. However, owing to the relatively small port openings made, it is correspondingly less in amount, and, as the openings are controlled in unison with and in the same manner as the ordinary service ports, the graduating feature of the valve is unimpaired and the very serious effect of increase of brake pipe volume is largely neutralized.

Uniform Release Feature.

To obtain a uniform release of the brakes on a long train, it is necessary to reverse what appears to be the natural order of things. For when high pressure air is admitted to the brake pipe in order to incease its pressure and release the brakes, the end of the pipe nearest the brake valve must necessarily feel the impulse first, and this impulse must travel progressively from the head to the rear end of the train, an action which is inherent and which necessarily results in the triple valves at the head end of the train moving to release position first. But this is the reverse of what is desired, which is to release the brakes at the rear as soon, if not sooner, than those at the head end. There are two possibilities here—either the release of the brakes at the rear must be hastened, or those at the head end held back to give the rear brakes a chance to overtake them. From what has just been said it is evidently impossible, with a purely pneumatic single-pipe system, to move the triple-valve piston at the rear end of a long train without first affecting those at the head end. Moreover, any supplementary source of air supply located at the rear end of the train which might be used to hasten the recharge at the rear not only fails to assist in hastening the release of the rear brakes, but introduces a factor contrary to the fundamental principle of the air brake, which is that any failure of the apparatus must be on the side of safety rather than danger.

Admitting that the triple valve pistons at the head end of the train must move before those at the rear, there remains the possibility of retarding the release of the head brakes in order to permit those at the rear to overtake the former and so produce a uniform release on the train as a whole. This has been accomplished by prolonging the triple valve exhaust cavity in the form of a restricted groove, so that when moved beyond release position the brake cylinder is forced to exhaust through this restricted port. When in release position, the slide valve is in contact with a stem held in position by a spring equal to about three pounds pressure on the piston. Toward the rear of the train the rise in brake pipe pressure is not sufficiently rapid to establish enough differential pressure on the triple valve piston to compress the spring above referred to, and the slide valve consequently remains in release position, allowing the air in the brake cylinder to exhaust freely to the atmosphere. Toward the head end of

the train, however, there is a more rapid rise of pressure on the brake pipe side of the triple valve piston, and this at once causes a differential sufficient to force the piston to the retarded release position, compressing the spring and retarding the release of the brake by forcing the exhaust to take place through the restricted exhaust port of the slide valve. In this manner the brakes at the head end of the train are, in their endeavor to release promptly, made to over-reach themselves, so to speak, and defeat their own purpose to the advantage of the train as a whole.

Uniform Recharge Feature.

Having introduced this new position, retarded release position, it was a simple matter to so arrange the charging ports of the triple valve that the recharge of the auxiliary reservoir should be restricted in this position in the same manner as the brake cylinder exhaust, and thus permit the flow of a much greater volume of air and at a higher pressure toward the rear end of the train than would be the case if each auxiliary reservoir was drawing its normal amount of air from the brake pipe. It will at once be observed here that the primary object of restricting the flow of air to the reservoir at the head end of the train was not to delay the recharging of the head auxiliary reservoirs as compared with those at the rear, but to take full advantage of the possibility which such an arrangement afforded of thereby insuring a more positive rise of brake pipe pressure toward the rear end of the train, and, therefore, a more prompt release of the rear brakes and quicker recharge of *their* auxiliary reservoirs, the net result being, as has already been explained, a greater uniformity of release and a more rapid and uniform recharge for the train as a whole.

Having shown the importance of the braking problem and how it has been solved, both in its past and present phases, it now remains to show that the improvement claimed for the new equipment, with respect to brake operation and train control, was actually obtained and could be demonstrated. The remainder of the paper accordingly treats of results obtained, comparing the old and new equipments, both as to the operation of the brake as a device and also from the standpoint of train control in actual service. We wish to say in this connection that the curves here shown fairly represent the careful and scientific character of the modern methods of analysis, by the aid of which the braking problems of the present have been solved, and, as a whole constitute a record of comparative brake performances unique in the progress of the art.

All of the following curves which show brake cylinder and brake pipe pressure on individual cars were taken by either indicators or pressure recorders and, therefore, represent actual results. The other curves, showing time of application, release, etc., for the train as a whole, have been plotted from the indicator records of the individual cars. The charts are arranged more or less in logical order to show—1st, the fundamental principles involved; 2nd, to illustrate the rise and fall of brake pipe and brake cylinder pressures in long and short trains, both with the old and the new equipment; 3rd, the results of these improvements in actual service.

FIGURE NO. 50.

Fig. 50 illustrates in a striking manner the influence of length of train and volume on the movement of the air in the brake pipe. It would naturally be assumed that if one end of the brake pipe were opened fully to the atmosphere, the pressure would fall very rapidly throughout the whole length of the train. But, as will be seen from Fig. 50, this is not the case. For here the brake valve was placed in emergency position, and while the fall of pressure at the head end of the train was very rapid, a considerable period elapsed before the reduction affected the pressure toward the rear of the train. Pressure indicators on the 1st, 15th, 30th, 50th, 75th, and 100th cars showed that after the brake valve handle had been in emergency position for 5 seconds, although the brake pipe pressure on the first car had fallen to 39 lbs., no evidence of fall yet appeared on the 40th car or any back of that car. In fact, it took about 15 seconds to drop the pressure 1 lb. on the 100th car, at which time the brake pipe pressure had fallen 43 lbs. on the 1st car; after which time it is interesting to note that the *rate* of reduction was nearly uniform on all cars in the train, thus keeping the difference in pressure on the head and rear end of the train about the same, viz., 42 lbs. to 43 lbs. The results of thus fully applying the brakes at the head end of the train before any have started to apply beyond the 40th car, if permitted to exist in actual practice upon a train, are too obvious to require comment. In fact, this graphically illustrates what made necessary, 1st, the quick action feature of the triple valve to promptly apply the brakes in emergency, and 2nd, the quick service feature for service operation. At the same time explodes the idea that the application of the brakes on a long train can be hastened by enlarging the outlet from the brake pipe at any one place in the train, thus illustrating no less clearly the necessity for locally venting the brake pipe pressure, both in service and emergency, if the effect of increase in length of pipe and volume of air to be disposed of is to be neutralized.

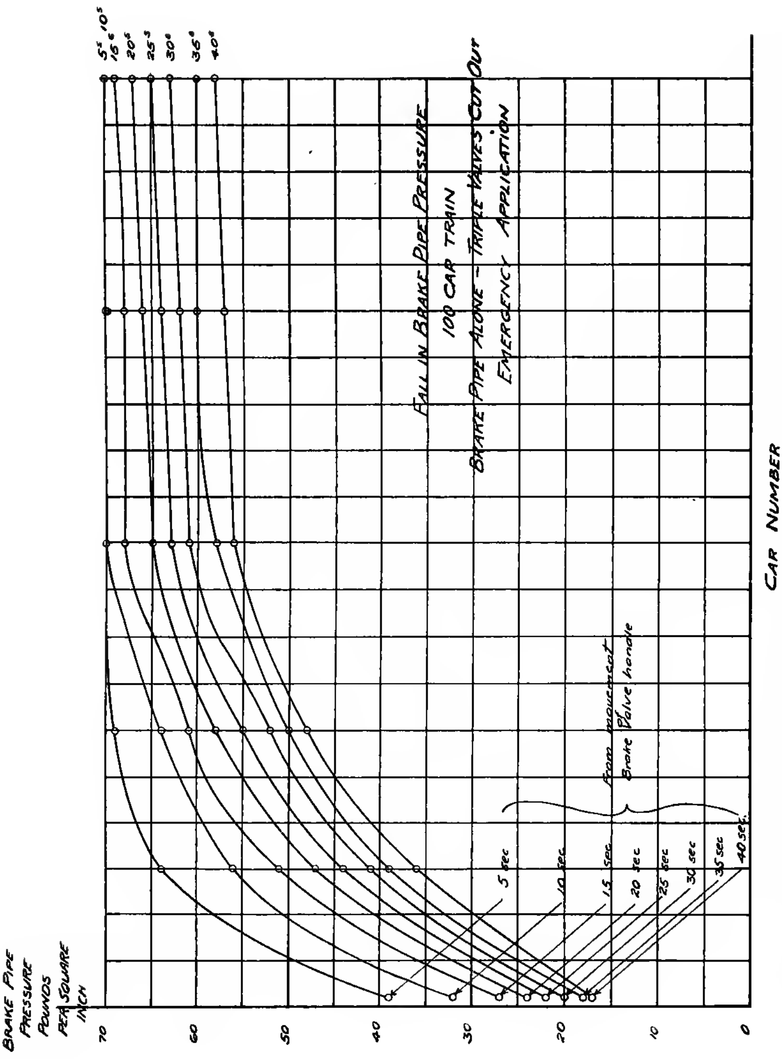


FIG. 50. RACK TEST. FALL IN BRAKE PIPE PRESSURE THROUGHOUT A TRAIN OF 100 CARS, 4000 FEET LONG; BRAKE PIPE ALONE; BRAKE VALVE HANDLE IN EMERGENCY POSITION.

FIGURE No. 51.

The data from which the foregoing curves were obtained, when plotted on a time base for individual cars in the train (Fig. 51), brings out still more forcibly the characteristics in the fall of brake pipe pressure in various parts of the train, and the relative pressures on the different cars indicated at any time during the reduction may be clearly seen. For instance, after 25 seconds had elapsed, the pressure on the first car had fallen 48 lbs., that on the 15th car 26 lbs., that on the 30th car 15 lbs., while on the 50th, 75th, and 100th cars the pressure had fallen only 7 lbs., 6 lbs., and 5 lbs., respectively, showing at this time, therefore, a difference of 43 lbs. in the brake pipe pressure on the 1st and 100th car; and illustrating, by the fact that the fall of pressure from the 50th car to the end of the train is practically uniform, that it is due more to *expansion than to flow*. This accounts for the difficulty experienced in applying the brakes toward the rear end of long trains when the brake pipe reduction is made in this manner, which, it should not be forgotten, was *through the largest opening possible, and is impracticable in service.*

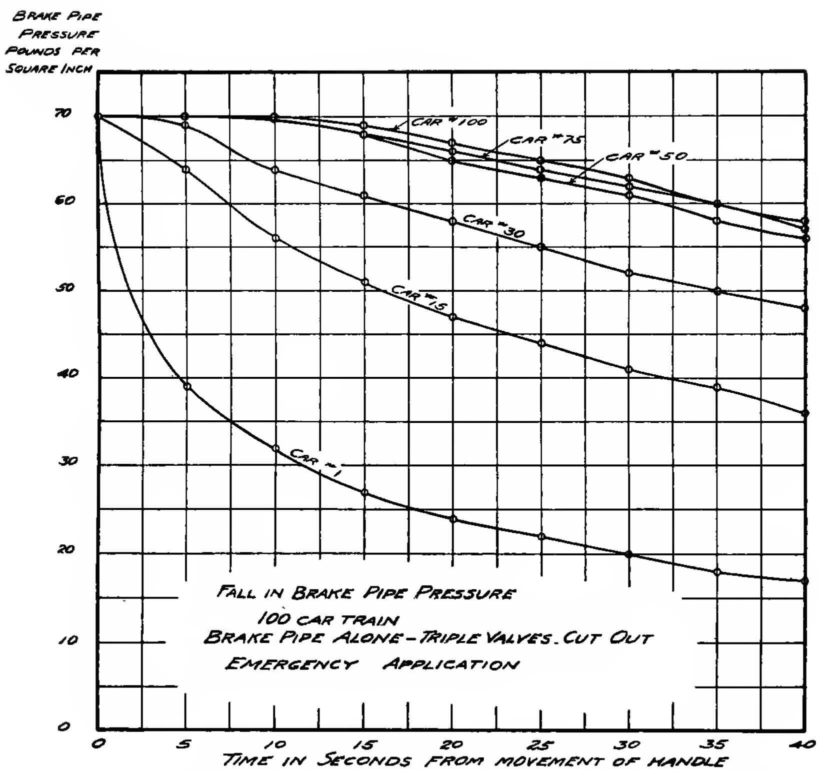


FIG. 51. RACK TEST. FALL IN BRAKE PIPE PRESSURE ON INDIVIDUAL CARS OF A 100-CAR TRAIN, 4000 FEET LONG; BRAKE PIPE ALONE; BRAKE VALVE HANDLE IN EMERGENCY POSITION.

FIGURE NO. 52.

Contrast the results as shown by Fig. 51 with those shown by Fig. 52 which represents in the same manner the results obtained using only the service position of the brake valve, but with the train equipped with the new type of triple valve, the difference in the relative positions of the individual curves composing the two sets being due to the quick service feature alone, and showing that the *necessary rate of reduction toward the rear of the train can only be obtained by means of locally venting the brake pipe pressure.* Taking the same time as for Fig. 51, viz., 25 seconds, the pressure on the first car had fallen 15 lbs., that on the 15th car 12 lbs., the 30th car 10 lbs., on the 50th and 75th cars 8 lbs., and on the 100th car, 7 lbs., showing a difference of only 8 lbs. (instead of 43 lbs.) in brake pipe pressure on the 1st and 100th cars.

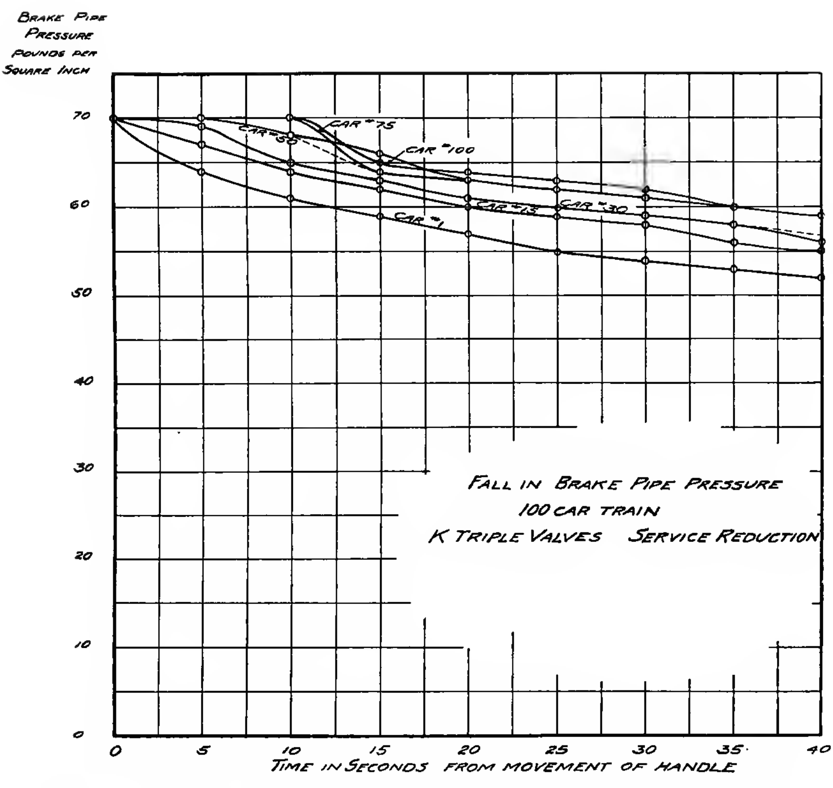


FIG. 52. RACK TEST. FALL IN BRAKE PIPE PRESSURE ON INDIVIDUAL CARS OF A 100-CAR TRAIN, 4000 FEET LONG; TYPE K TRIPLE VALVES; SERVICE REDUCTION.

FIGURE NO. 53.

Fig. 53 illustrates how the brake pipe pressure actually does fall in a full and continuous service application of the brakes with the old standard triple valves. The effect of this on the application of the brakes is shown and described in connection with Fig. 56 and following, but in passing it may be said that the brake pipe pressure had fallen to 55 lbs. at the head end of the train with consequent almost full application of the brake before sufficient reduction had taken place at rear to cause any movement of triple valves.

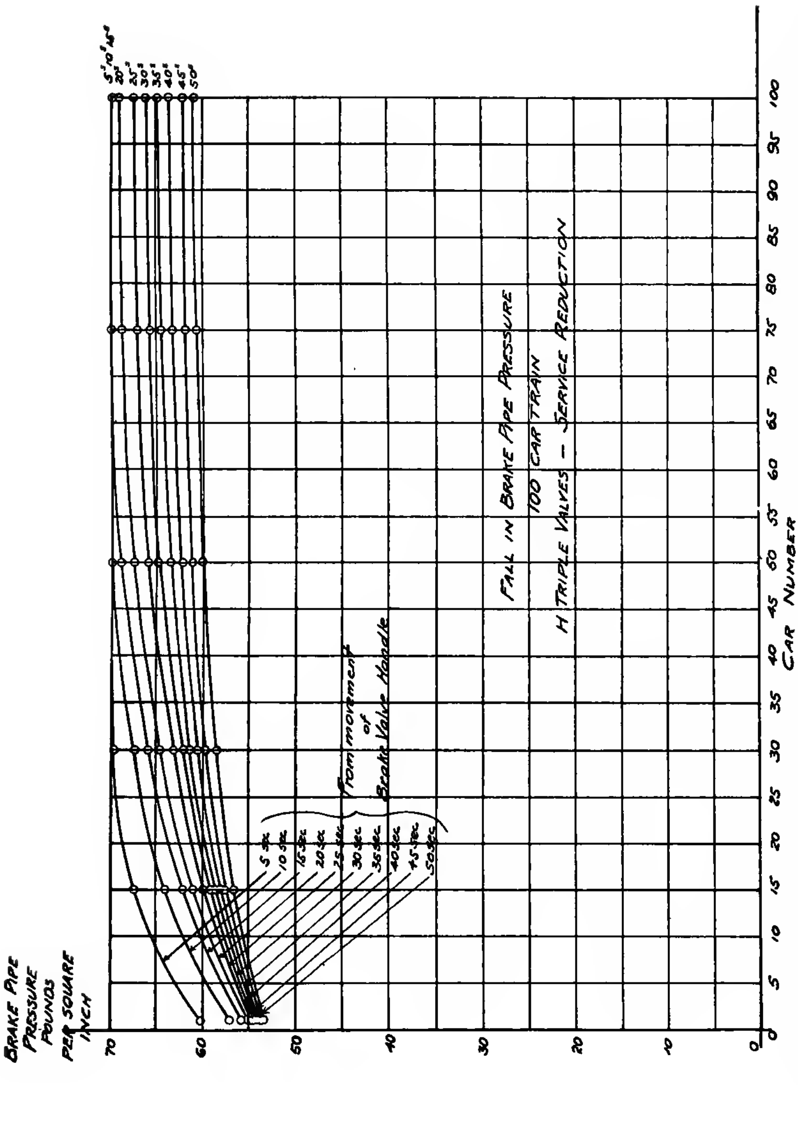


FIG. 53. RACK TEST. FALL IN BRAKE PIPE PRESSURE THROUGHOUT A 100-CAR TRAIN, 4000 FEET LONG; TYPE H TRIPLE VALVES; SERVICE REDUCTION.

FIGURE No. 54.

In contrast to the previous curves, Fig. 54 illustrates the influence of the quick service feature upon the service application of the brakes, for here it will be seen that when the pressure at the head end of the train had fallen to 55 lbs., that at the rear was down to 62 lbs., with consequently an effective application of all the brakes in the train. A characteristic to be particularly noted in connection with Figs. 53 and 54 is that the fall of pressure to 55 lbs. on the first car required the same time, 25 seconds, in each case. Therefore, this proves conclusively that the effect of the quick service feature is to make the rate of reduction of pressure more uniform throughout the train.

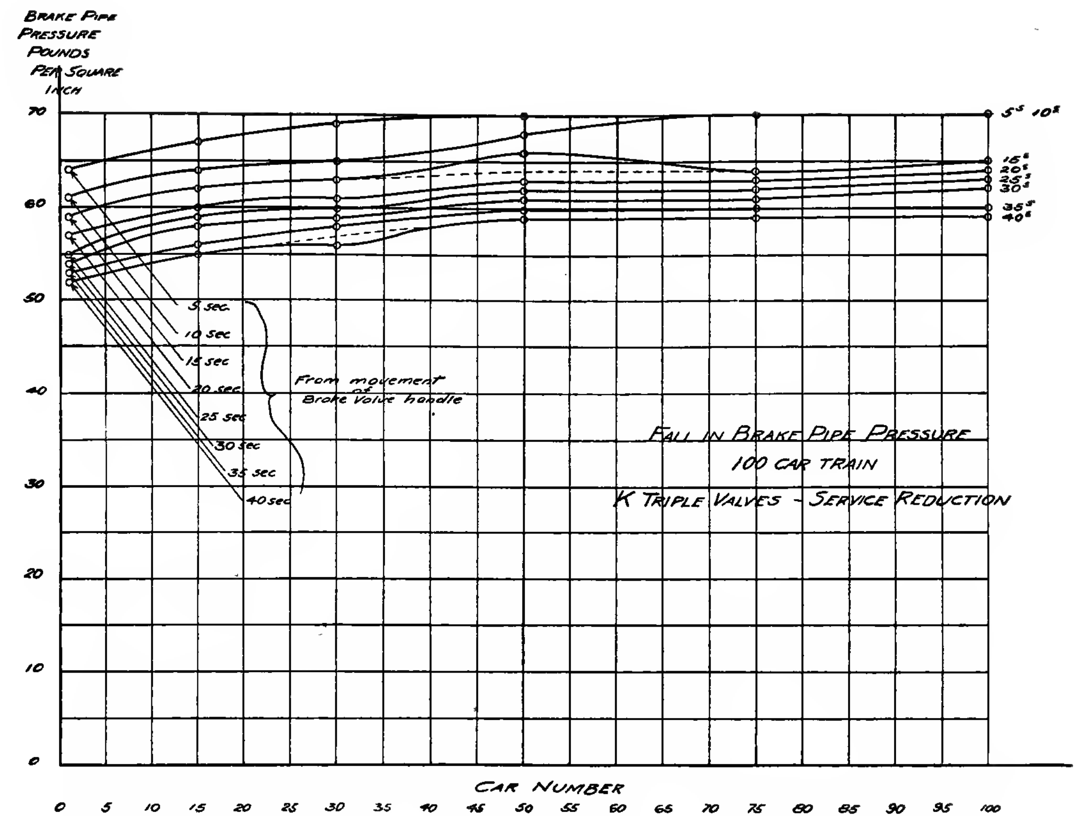


FIG. 54. RACK TEST FALL IN BRAKE PIPE PRESSURE THROUGHOUT A 100-CAR TRAIN, 4000 FEET LONG; TYPE K TRIPLE VALVES; SERVICE REDUCTION.

FIGURE NO. 55.

Having shown how the pressure in the brake pipe falls, and that it is unaffected by the old type valve but is favorably affected by the new type of valve, it remains to contrast for each the rate at which a reduction travels back through the train, and this is shown on Fig. 55. For the new valves the curve closely approximates a straight line, while that of the old valves shows that the outlet at the brake valve is slow in affecting the brake pipe pressure beyond the middle of the train, notwithstanding the fact that the outlet in this case was governed by a variable lift equalizing piston giving a maximum opening twice that allowed in regular service.

As a matter of fact, the attempt to hasten the reduction of brake pipe pressure by this method, after being thoroughly tried out, was abandoned because it could not be made to produce the desired results, and means for locally venting the brake-pipe pressure on each car was devised and developed in its stead.

As is often the case after a thing is done, it is now seen that this is the logical and only way in which a quicker and more uniform brake pipe service reduction can be obtained.

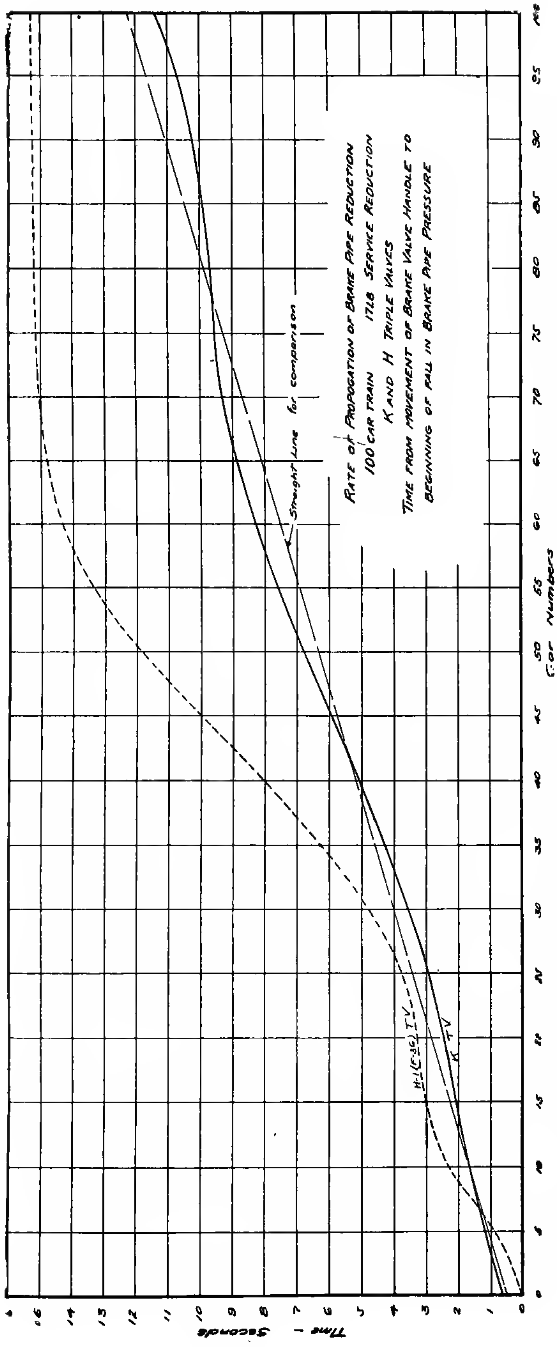


FIG. 55. RACK TEST. RATE OF PROPAGATION OF BRAKE PIPE REDUCTION THROUGHOUT A TRAIN OF 100 CARS, 4000 FEET LONG; TYPES H AND K TRIPLE VALVES; SERVICE REDUCTION.

FIGURE NO. 56.

The effect of the different rates of reduction as just described and the reason for the improvement in train handling secured thereby is illustrated in Fig. 56, where a 5-lb. reduction is made with a 100-car train equipped with each type of brake. It will be seen that with the old type of valves no effective application of the brake was obtained on any car in the train, ten brake pistons failing to move at all, and it took 45 seconds to obtain a movement of the brake piston on the 100th car, while with the new type of valve an effective brake application was obtained on all cars in the train the 100th brake applying in ten seconds time.

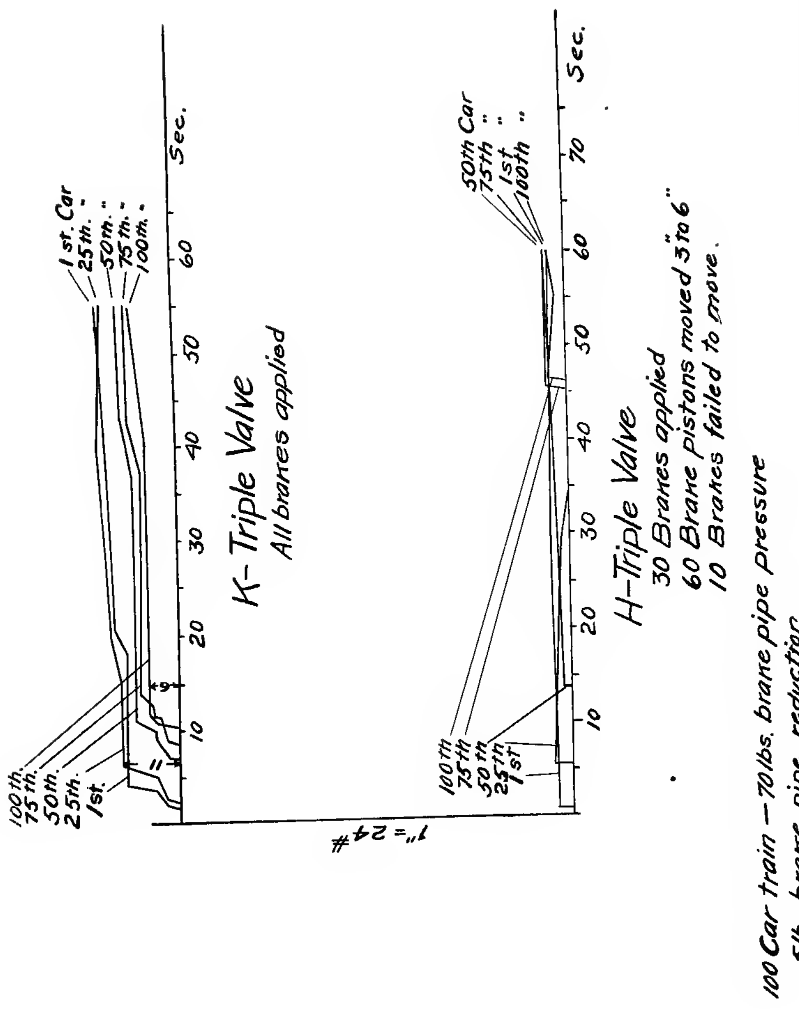


FIG. 56. RACK TEST. BRAKE CYLINDER CARDS SHOWING APPLICATION CURVES OF H AND K TRIPLE VALVES ON A LONG TRAIN, 100 CARS; 5 LB. BRAKE PIPE REDUCTION.

FIGURE No. 57.

The curves shown in Fig. 57 are similar to those of Fig. 56, but for a 10-pound service reduction, and illustrates how much more effective the average reduction is, both in cylinder pressure obtained and the time required to obtain it, with the new type of valve as compared with the results obtained with the older valve; and at the same time furnishes the reason why so much better train control is had with the new than with the old type of equipment.

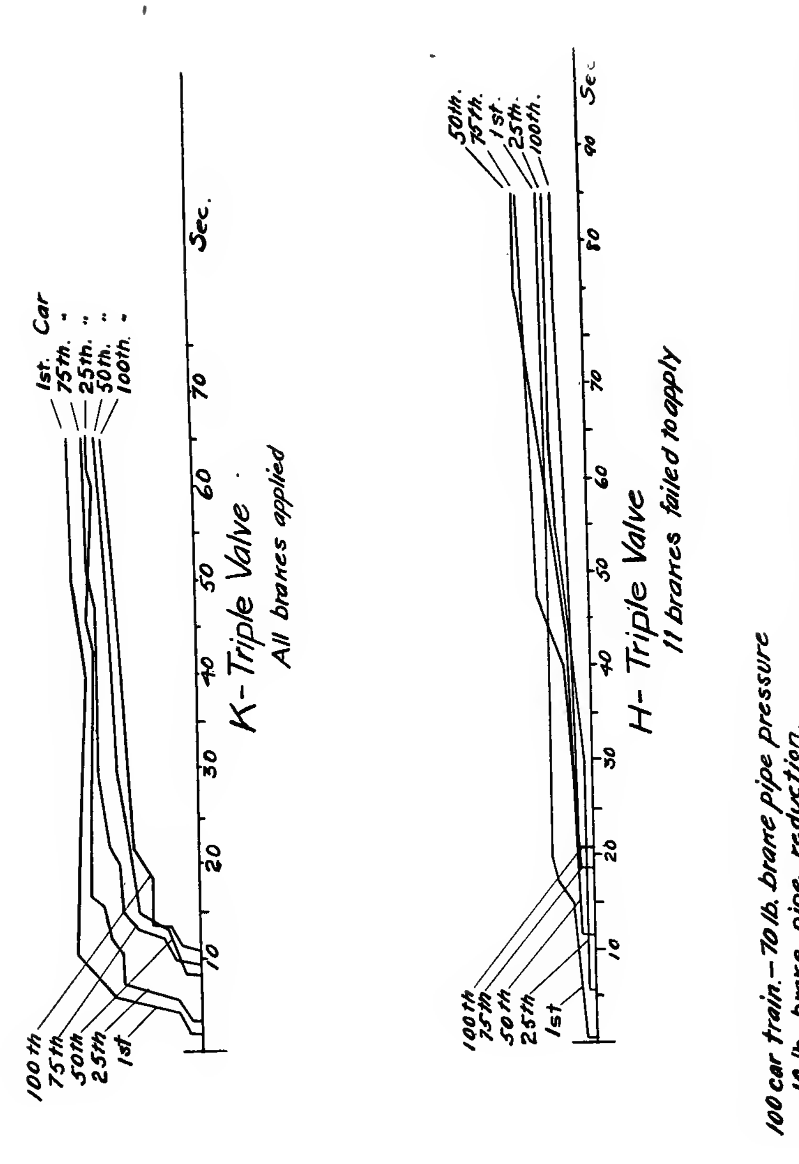


FIG. 57. RACK TEST. BRAKE CYLINDER CARDS SHOWING APPLICATION CURVES OF H AND K TRIPLE VALVES ON A LONG TRAIN, 100 CARS; 10 LB. BRAKE PIPE REDUCTION.

FIGURE NO. 58.

Fig. 58 continues the comparison, showing the results obtained from a 15-pound reduction.

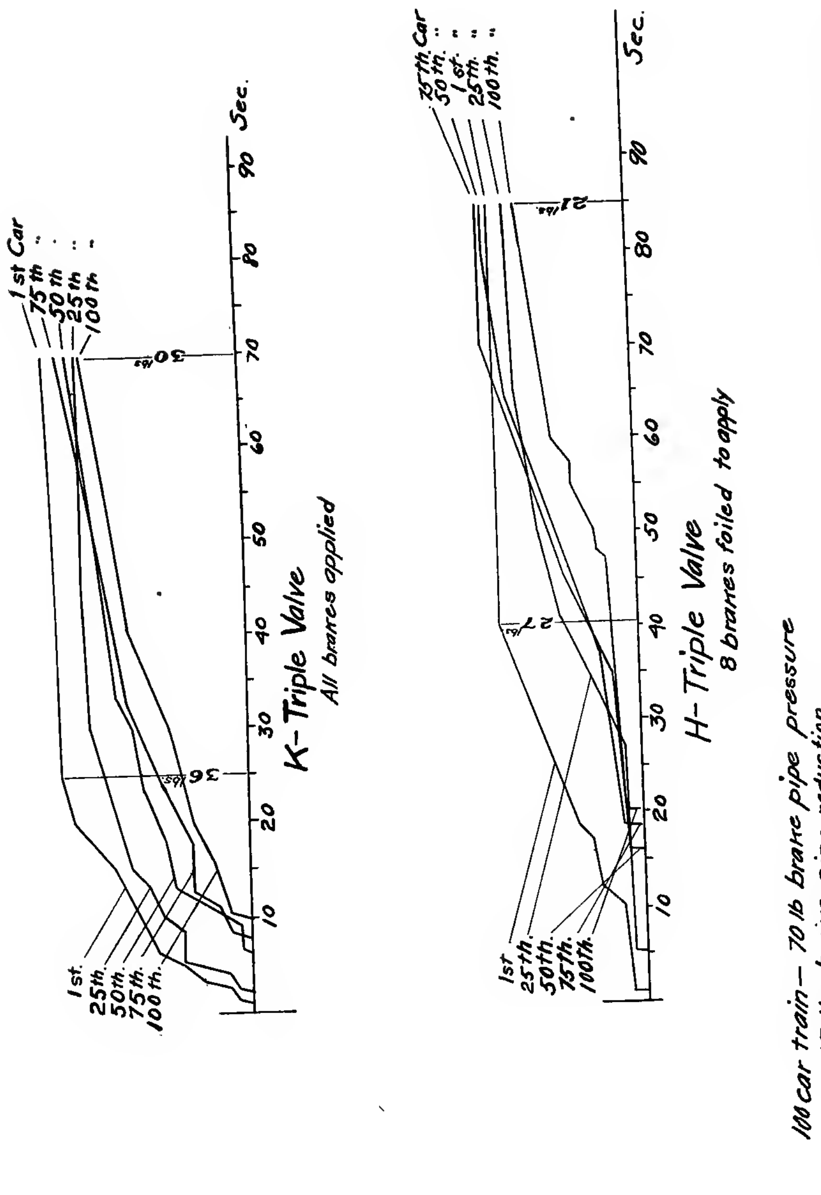


FIG. 58. RACK TEST. BRAKE CYLINDER CARDS SHOWING APPLICATION CURVES OF H AND K TRIPLE VALVES ON A LONG TRAIN, 100 CARS; 15 LB. BRAKE PIPE REDUCTION.

FIGURE NO. 59.

Fig. 59 carries the comparison still further, and shows the results obtained on a continuous 20-pound or maximum service reduction. It will here be seen on the cards for the "K" valve—1st, that not only do the brakes apply more nearly as on the shorter trains of times gone by (see Fig. 62, showing this action on a 31-car train), but that the cylinder pressure obtained is more nearly what it should be; and 2nd, that notwithstanding the maximum service reduction was made, 6 brakes failed to apply on the train equipped with the old type of valve, while not a single brake failed to apply on the train equipped with the new valve, from and including the 5-pound reduction upward.

In this connection, as well as referring to Figs. 56, 57, and 58 we wish to call your particular attention to the "toe" of the diagrams showing the rise of cylinder pressure with the "H" triple valve. This shows that it takes a number of seconds for the pressure to build up in the brake cylinder sufficiently to force the piston to its full travel and begin to exert effective braking power. As would be expected, this characteristic is more marked on the rear cars of the train. With the "K" valves, however, even for the light reductions, and on the last car in the train, the cylinder pressure line rises positively in every case, showing that the influence of the quick service feature is to insure a movement of the brake cylinder piston to full travel and the development of an effective braking power on every car no matter what the reduction may be or where the car may be located in the train.

It will be seen from all the indicator cards and diagrams taken with the "K" triple valve that the application of the brake and the rise of cylinder pressure up to, say, 20 lbs. is obtained much more quickly on any length of train with the new valves than with the type "H" valve. It will be seen also that with the "K" valves the rate of rise of cylinder pressure *after* about 20 lbs. has been reached is little, if any, greater than with the "H" valves. This very necessary feature was difficult to obtain, but its importance cannot be over-estimated, for first, it is necessary to get the brakes to apply and with an effective cylinder pressure, after which it is just as important that a further rise of cylinder pressure take place slowly, in order to prevent sudden severe strains being set up as the slack is adjusting itself. Thus, on account of the quicker initial rise of brake cylinder pressure and the uniformity of application of all the brakes in the train the necessity for making heavy reductions, as are required with the "H" valves, no longer exists, and the brake applications necessary to bring the train under control under these new conditions are not heavy enough to produce excessive strains in the train.

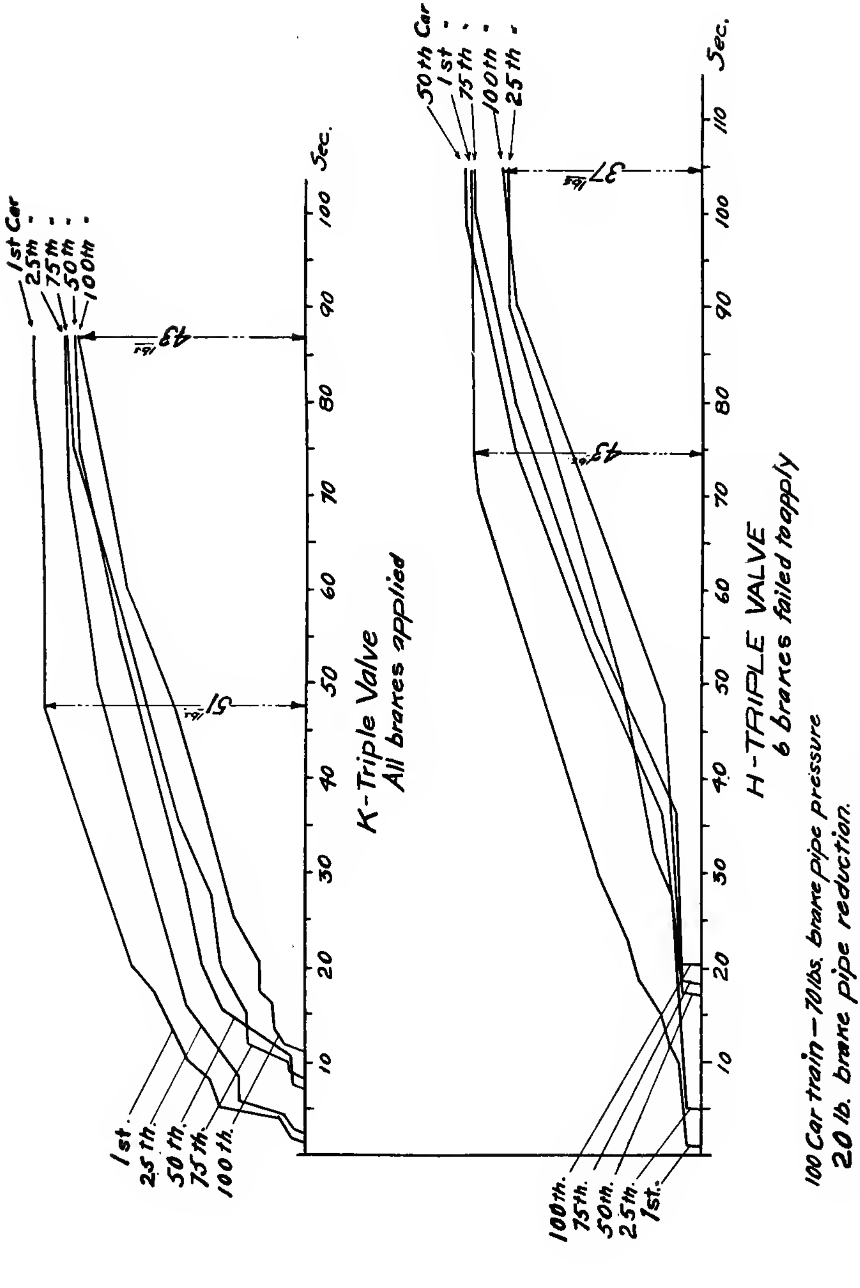


FIG. 59. RACK TEST. BRAKE CYLINDER CARDS SHOWING APPLICATION CURVES OF H AND K TRIPLE VALVES ON A LONG TRAIN, 100 CARS; 20 LB. BRAKE PIPE REDUCTION.

FIGURE NO. 60.

Up to this point the characteristics of the new and old types of triple valves have been contrasted—1st, as to the rate of brake pipe reduction obtained, and 2nd, as to the effect of this upon the application of the brakes, both as to certainty and time of application, but so far no specific reference has been made to the difference in time required to obtain effective braking power. From records taken during a long series of public demonstrations with an 80-car rack, the curves of Fig. 60 have been plotted to illustrate the relative time in which 20 lbs. cylinder pressure is obtained in the 1st, 50th, and 80th cars of a train of this length, with the new and old triple valves. It will be seen that with the "H" triple valves, 20 lbs. was obtained in the brake cylinder on the 1st car in 25 seconds, while the same pressure was obtained with the "K" triple valves in 17½ seconds. On the 50th car, with the "H" triple valves, it took 93 seconds to obtain 20 lbs. cylinder pressure, while with the "K" valves the same pressure was obtained in 37 seconds, and on the 80th car, with the "H" valves, it took 95 seconds, while with the "K" valves only 39½ seconds were required. Thus 20 lbs. cylinder pressure was obtained in the brake cylinder on the last car of the train 55½ seconds sooner with the new than with the old valves, or before 20 lbs. was obtained on the 20th car of the train equipped with the old valves. The difference in the effects produced in the two cases with regard to bunching of slack and recoil is too evident to require comment.

In order that it may not be thought that the curves of Fig. 60 have been plotted to show the widest extremes during the series of tests, we wish to mention that the contrary is the case. As a matter of fact, the times shown for the "H" valves are the shortest which were obtained, but there were times during this series of demonstrations when the time required to obtain 20 lbs. cylinder pressure on the 50th and 80th cars ran as high as 160 seconds each, with the results of the other tests ranging between these two extremes. For the "K" valves, however, the results were remarkably uniform throughout, and it cannot be too strongly emphasized that this is a characteristic difference between the two types of valves.

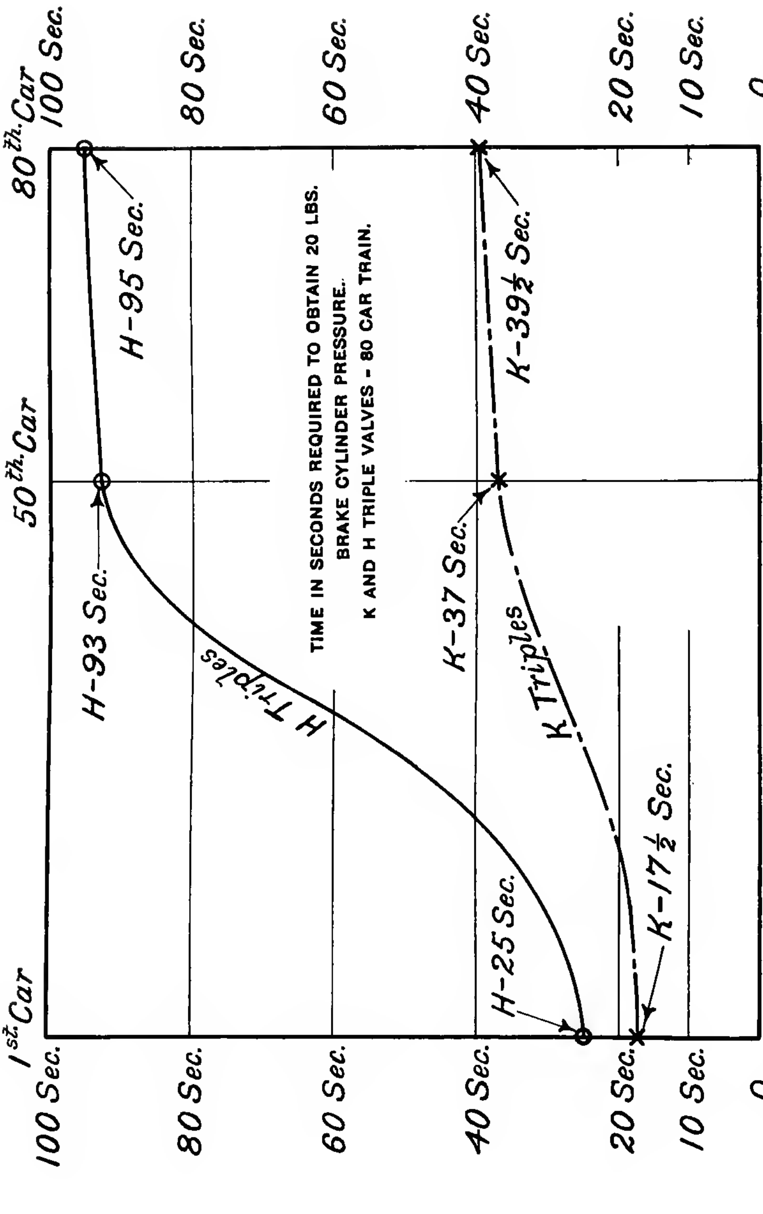


FIG. 60. RACK TEST. TIME TO OBTAIN 20 LBS. BRAKE CYLINDER PRESSURE WITH OLD AND NEW TRIPLE VALVES ON AN 80-CAR TRAIN.

FIGURE NO. 61.

To the end that all may appreciate the effect of length of train and volume of air on the action of brakes, Figs. 61, 62, and 64 have been plotted, which show curves similar to those just described, the manipulation and conditions during the test being alike except that the train was reduced to 31 cars, instead of being 100 cars. As the difference between the conditions governing the operation of the brakes in the past and those which it has to meet today lies wholly in what is responsible for the difference between the diagrams of Figs. 61 to 64 and those of Figs. 50 to 60, viz., the length of the train and volume of air, you are particularly requested to compare and analyze the effect shown for similar operations with the long and the short trains. We wish to assure you that this involves more than appears on the surface, but your most painstaking efforts will be amply rewarded; and unless what is involved in this comparison is understood, at least to the extent of the law in the case, no one can fully appreciate why the changed conditions compelled us to add new features to those already possessed by the old brake.

For example, the right-hand diagram of Fig. 61 shows that with a 31-car train the brake pipe pressure had fallen 23 lbs. on the last car in 15 seconds, at which time there was a difference of only 16 lbs. between the brake pipe pressure on the first and last cars, while with the 100-car train in the same time the brake pipe pressure on the last car had fallen only 1 lb., and to make matters still worse, there is a difference of 42 lbs. between the brake pipe pressure on the first and last cars. That you may not attribute this to increase of volume alone, it is important to note that with a train 3⅓ times as long, the rate of reduction is only 1/23 that with the shorter train. These examples but typify the information which can be obtained by continuing this analysis, which time will not permit of our doing to-night.

The left-hand diagram of Fig. 61 for the short train should, in a similar manner, be compared with Fig. 51 for the 100-car train, both being drawn to the same scale.

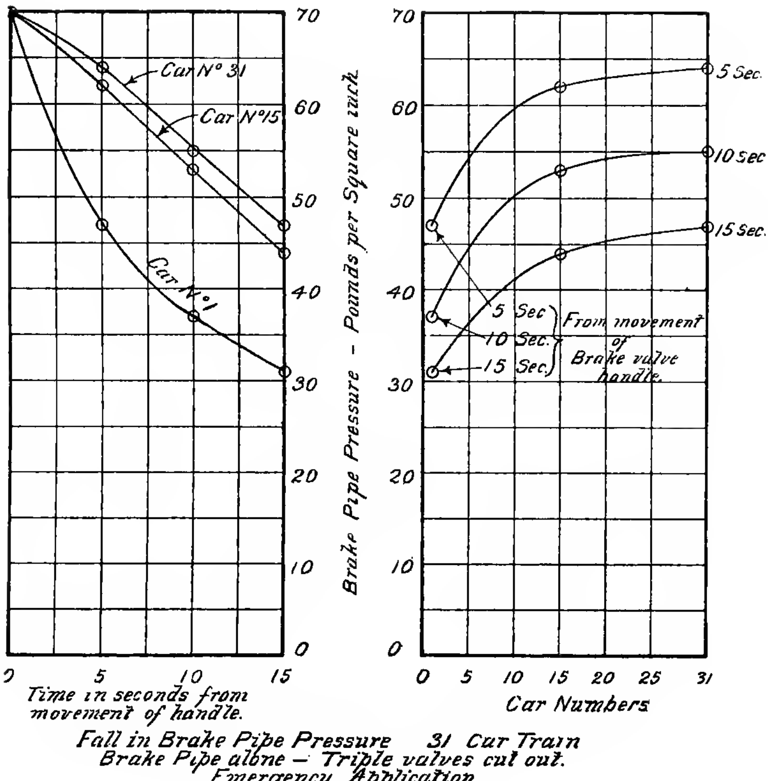


FIG. 61. RACK TEST. FALL IN BRAKE PIPE PRESSURE THROUGHOUT A 31-CAR TRAIN, 1240 FEET LONG; BRAKE PIPE ALONE; BRAKE VALVE HANDLE IN EMERGENCY POSITION. SCALE SAME AS FOR FIGS. 50 TO 54.

FIGURE No. 62.

Fig. 62 for the short train corresponds to Fig. 56 to Fig. 59 for the 100-car train, and shows how the time, not only to apply the brakes but to obtain effective braking power, is affected by the length of the train. As these differences are so apparent when the curves are contrasted, it is only necessary to point out here that with the 31-car train there is no difficulty in applying all the brakes, with a 5-lb. reduction, and that the last brake is applied in 6 seconds, while, when a 20-lb. reduction is made, full service braking pressure is obtained in 37 seconds. On the other hand, with the 100-car train, and the same type of triple valve (Type "H"), only 30 brakes gave any braking power with the 5-lb. reduction, the movement of the 100th brake not occurring until 45 seconds had elapsed. Furthermore, on a 20-lb reduction, full braking power was not obtained on the last car for 105 seconds, and even then the pressure obtained was 13 lbs. less than on the last car of the short train. This difference represents the loss due to the necessarily much slower rate of reduction on the long train.

You can readily see that many other very interesting and instructive comparisons of this nature can be made.

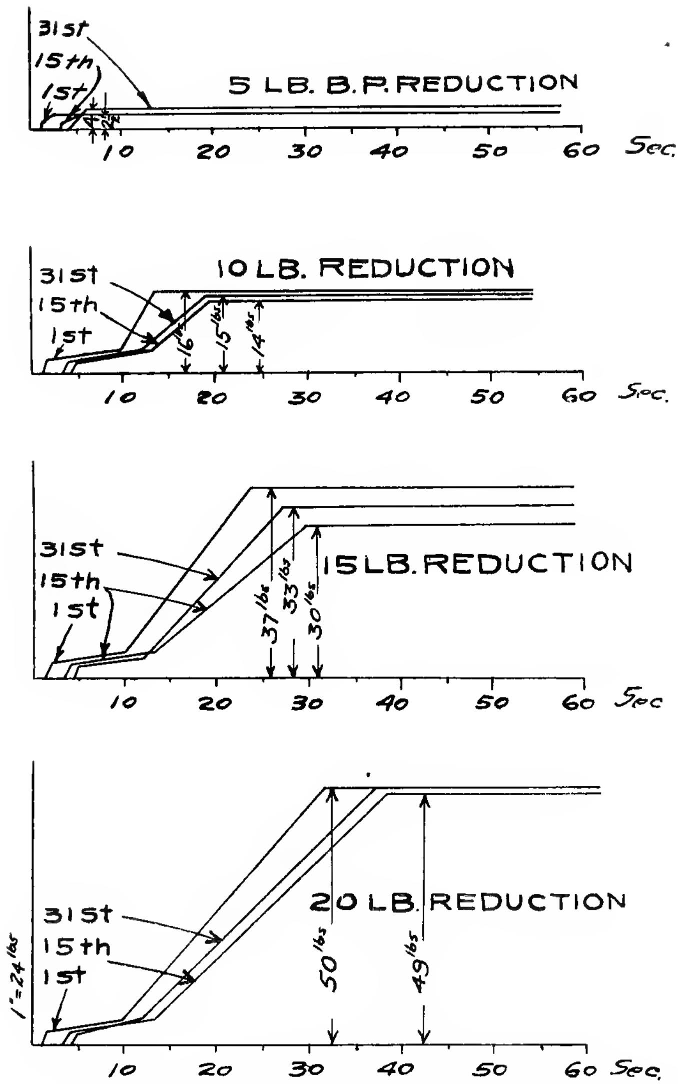


FIG. 62. RACK TEST. BRAKE CYLINDER CARDS SHOWING APPLICATION CURVES OF H TRIPLE VALVES ON A SHORT TRAIN; 31 CARS. SCALE SAME AS FOR FIGS. 56 TO 59.

FIGURE NO. 63.

Fig. 63 shows curves similar to those of Fig. 62, but for type "K" instead of type "H" triple valves, and should also be compared with the "K" triple valve cards of Figs. 56 to 59 to appreciate the effectiveness of the improved valve on short, as well as on long trains. Comparing Figs. 62 and 63, it is seen that even on trains of ordinary length the type "K" valve is much more effective on light reductions than the "H" valves, thus insuring a definite retarding power for light reductions and establishing a sufficient differential between the brake pipe pressure and the setting of the feed valve to permit of a proper release being made. For the 15-lb. and 20-lb. reductions, however, the difference between the type "K" and "H" valves is not so noticeable, though the pressures obtained with the type "K" valve are somewhat more uniform.

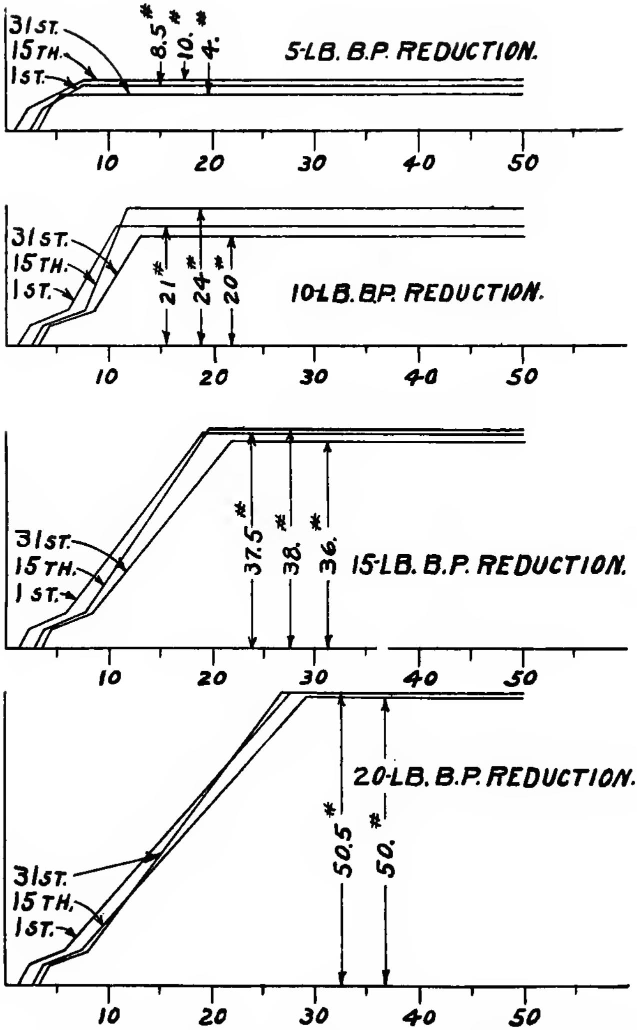


FIG. 63. RACK TEST. BRAKE CYLINDER CARDS SHOWING APPLICATION CURVES OF K TRIPLE VALVES ON A SHORT TRAIN; 31 CARS. SAME SCALE AS FIG. 62.

FIGURE No. 64.

To contrast the times required to obtain effective braking power on short and long trains, compare the full line of Fig. 60 with Fig. 64, which shows the time required with H triple valves to obtain 20 lbs. cylinder pressure on the 1st, 15th, and 31st cars of the 31-car train. Here we see that not only does the length of train render more difficult the obtaining of the difference of pressure which must be had to operate the triple valves, but even after this difference is obtained, the cylinder pressure cannot rise more rapidly than the brake pipe pressure is falling. Do we really appreciate what it means when 20 lbs. is obtained in 20 seconds in the one case and not for 75 *seconds thereafter* in the other?

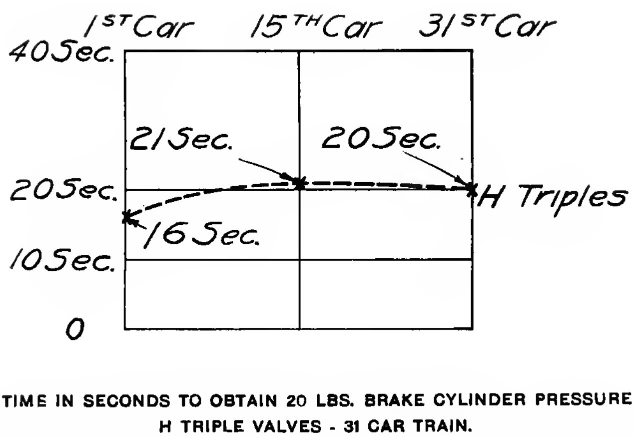


FIG. 64. RACK TEST. TIME TO OBTAIN 20 LBS. BRAKE CYLINDER PRESSURE WITH H TRIPLE VALVES ON A 31-CAR TRAIN. SCALE SAME AS FOR FIG. 60.

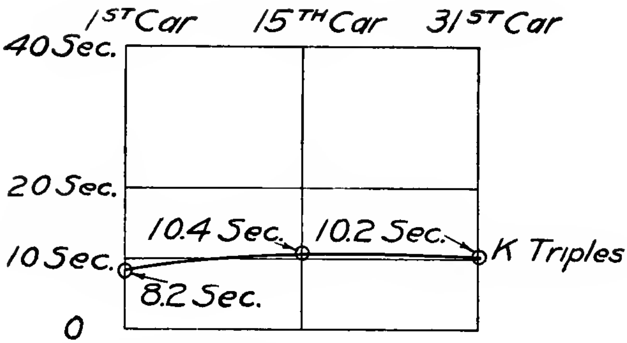


FIG. 65. RACK TEST. TIME TO OBTAIN 20 LBS. BRAKE CYLINDER PRESSURE WITH K TRIPLE VALVES ON A 31-CAR TRAIN. SCALE SAME AS FOR FIG. 60.

FIGURE No. 65.

Fig. 65 for the 31 type "K" triple valves corresponds to Fig. 64 for the 31 type "H" valves, and shows in a striking manner the effect of the type "K" triple valve, not only in hastening the rate of brake application throughout the length of the train, but also in the promptness with which effective braking pressure is obtained. Comparing Fig. 65 with Fig. 64 it will be noted that effective braking power (20 lbs. brake cylinder pressure) was obtained with the type "K" triple valves in about one-half the time required by the type "H" valves. This fact alone is sufficient to establish the increased efficiency of the "K" valves for short as well as long train handling.

FIGURES NOS. 66 TO 69.

In order to avoid conveying the impression that the quick service feature of the "K" triple valve is only necessary or beneficial on trains of extreme length, the diagrams of Figs. 66 to 69 are given. These show the action of the "K" and "H" valves with respect to fall of brake pipe pressure and rise of cylinder pressure, both in time and amount, on a 50-car train, and for facility of comparison, the indicator cards of the two types of valves are shown superposed on the same diagram.

As Figs. 67 to 70 are the same in character but differ in the amount of reduction, an analysis of one set is all that is deemed necessary. Referring, for example, to Fig. 67 as being representative of the series, cards were taken from both the brake pipe and brake cylinder on the 1st, 25th, and 50th cars, the solid lines being the records of the "K" valves, the dotted lines of the "H" valves; all plotted on the same time base, the vertical scale being pressure in pounds per square inch, as indicated. The different brake pipe and brake cylinder pressures after intervals of 5, 10, and 15 seconds, are noted by the figures on each diagram, and as the comparison between the results with the two types of valves is so obvious, and corresponds to that already explained for longer trains, we believe that you will agrec with us that present time will be saved by leaving further consideration of this series for you to continue as leisure and inclination will permit.

Uniform Release.

As the pressure in the brake pipe falls more rapidly at the head end of the train when making a brake pipe reduction, as has been explained, so, conversely, the rise of the brake pipe pressure when a release is made is more rapid at the front than at the rear end because of its proximity to the source of supply and the natural frictional resistance to the flow of the air.

To compensate for this, the uniform release feature was added to the triple valve, the principles of which have already been explained. The characteristics of this feature are shown by the curves which follow. (See Fig. 70 and following.)

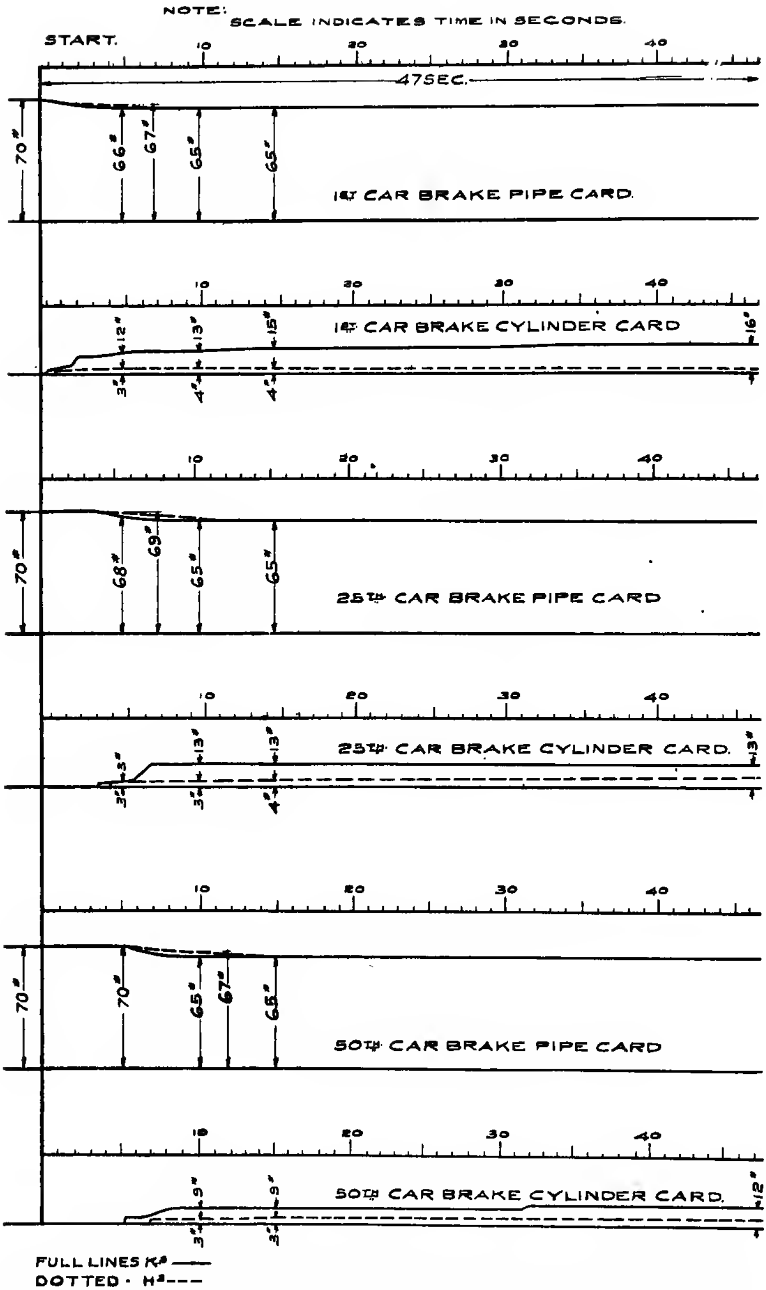


FIG. 66. RACK TEST. BRAKE PIPE AND BRAKE CYLINDER CARDS, 50-CAR TRAIN, H AND K TRIPLE VALVES. APPLICATION 5 LB REDUCTION

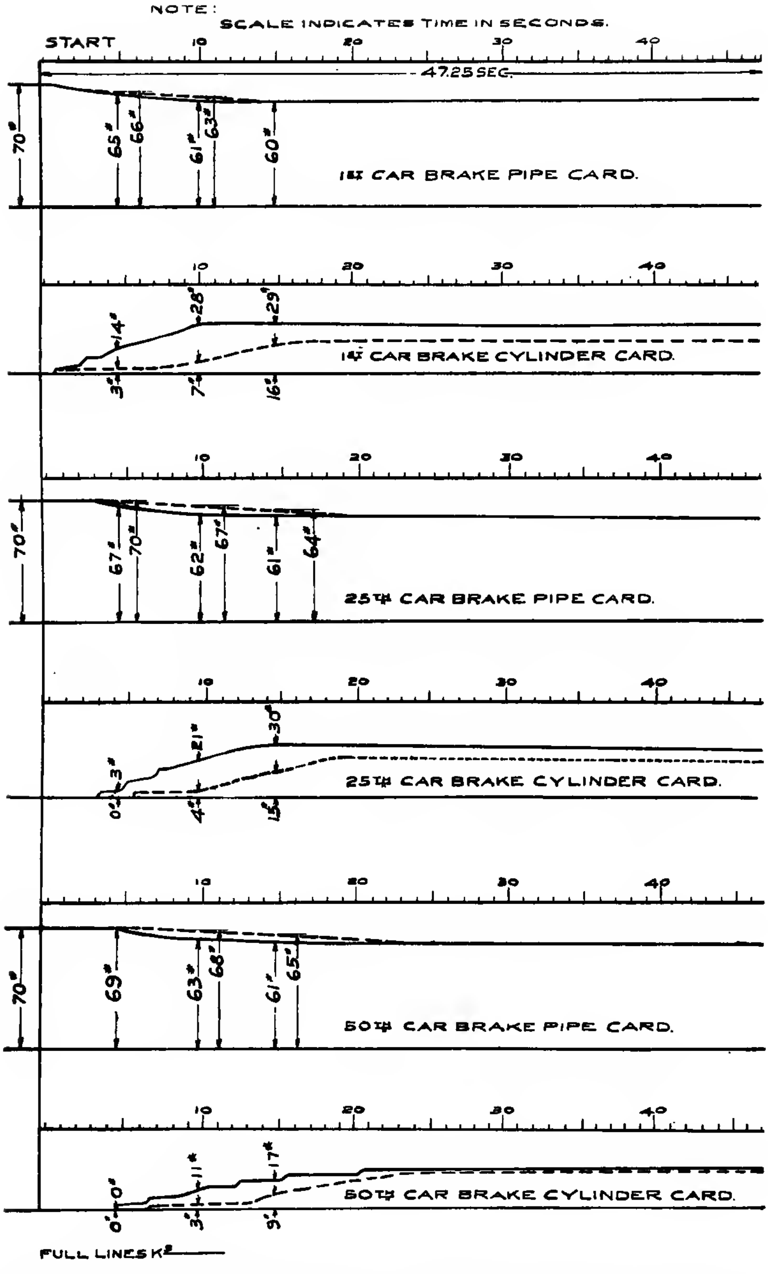


FIG. 67. RACK TEST. BRAKE PIPE AND BRAKE CYLINDER CARDS, 50-CAR TRAIN, H AND K TRIPLE VALVES. APPLICATION, 10 LB. REDUCTION.

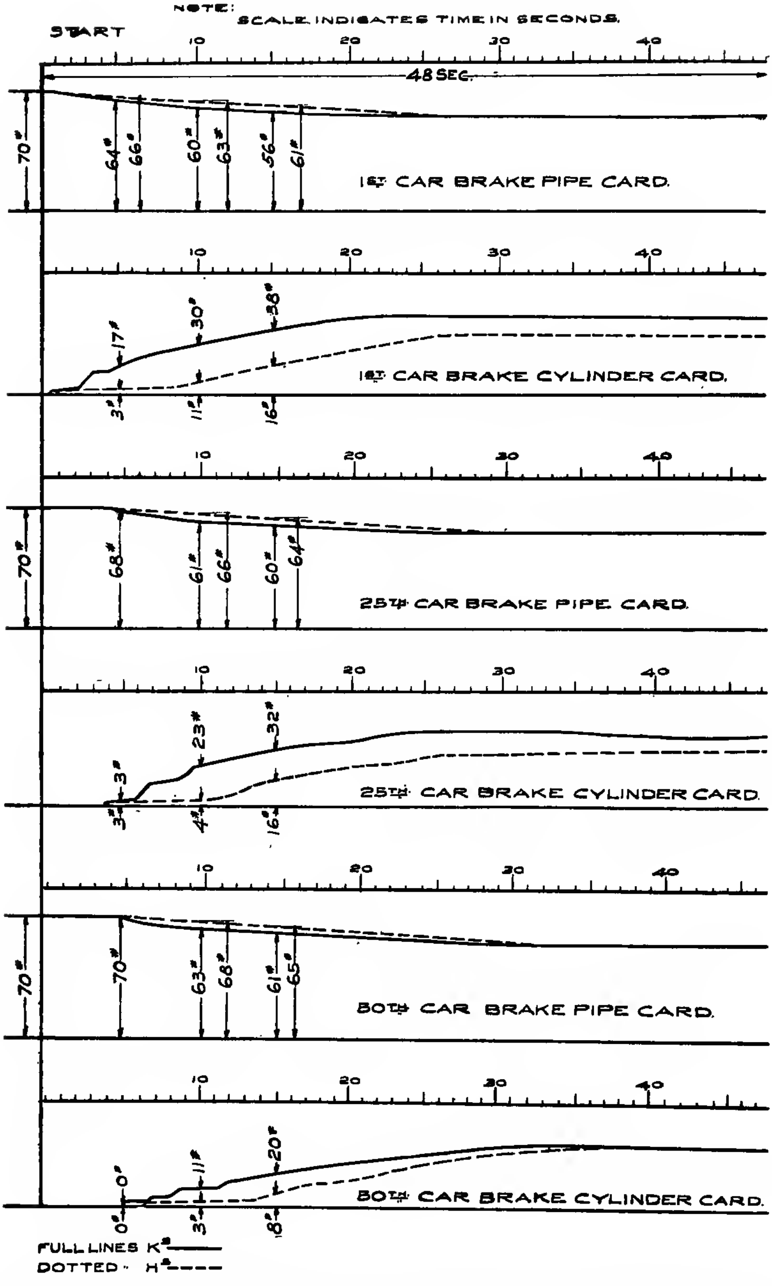


FIG. 68. RACK TEST. BRAKE PIPE AND BRAKE CYLINDER CARDS, 50-CAR TRAIN, H AND K TRIPLE VALVES. APPLICATION, 15 LB. REDUCTION.

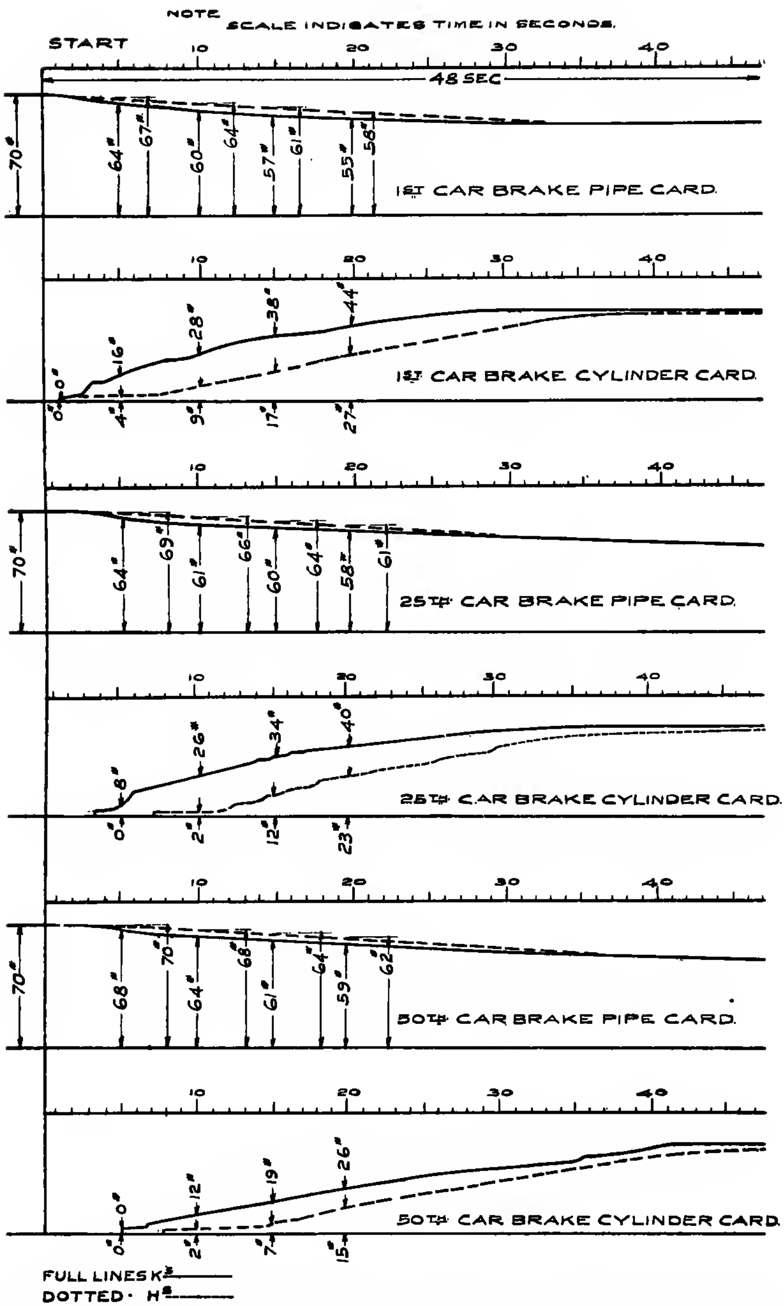


Fig. 69. Rack Test. Brake Pipe and Brake Cylinder Cards, 50-Car Train, H and K Triple Valves. Application, 20 lb. Reduction.

FIGURE NO. 70.

Referring to Fig. 70, it will be seen that when a release is made after a full service application of the brake on a train of 80 cars, the first brake of the train equipped with the old type of triple valves is released down to 5 lbs. cylinder pressure (when piston begins to return) in 3 seconds from the movement of the brake valve handle, the 50th in 13½ seconds, and the 80th in 21½ seconds. Thus it is clear that the first brake was released 18½ seconds before the last, so that for a considerable portion of this time full retardation was still being had on the rear cars of the train while the front cars would be running free if it were not for the strain on the drawbars.

Contrast with this the action of the "K" valves. Here the first brake did not release until 19 seconds had elapsed, the 50th releasing in 15½ seconds, while the 80th brake released in 15¾ seconds. Thus we see that in this case the head end was being retarded, to some extent at least, while the rear end would be running free if it were not for the tendency to compress the draft gear springs, which must necessarily be slight, owing to the fact that at this time the cylinder pressure is also low on the front cars.

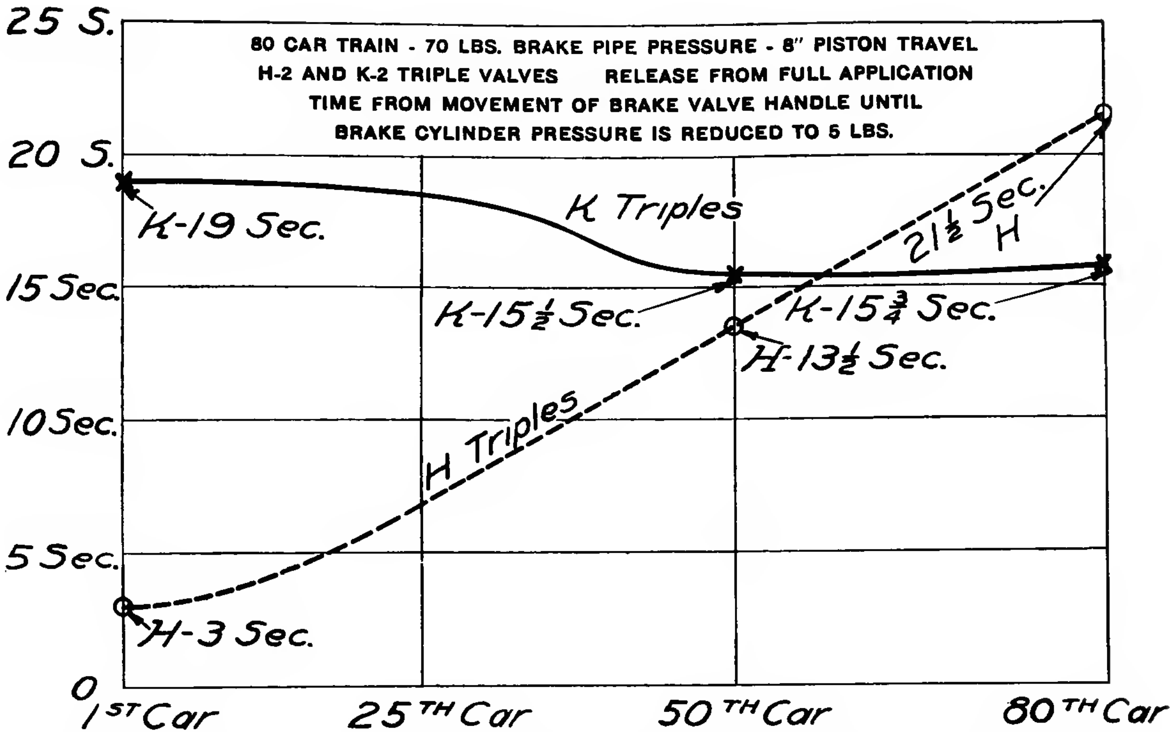


FIG 70. RACK TEST. TIME REQUIRED TO RELEASE BRAKES ON AN 80-CAR TRAIN, 3200 FEET LONG; K AND H TRIPLE VALVES.

FIGURE NO. 71.

To show the effect of the uniform release feature on a 50-car train, Figs. 71 to 76 are given. Referring to Fig. 71, brake cylinder cards were taken from the 1st, 25th, and 50th cars of trains equipped with both the "H" and "K" type of valve and plotted on the same base to facilitate comparison both of the release of the front and rear cars of the same train and of the release of the brakes of the "H" train with that of the "K" train. It will be seen that for the "K" train the release of the 1st brake commences in 0.6 seconds after the movement of the brake valve handle the 25th in 3.7 seconds, and the 50th in 7.9 seconds, yet, notwithstanding this order of commencement to release, the completion of the release is in the reverse order, due, as shown by the curve for the first car, to a much slower exhausting of the pressure from the brake cylinders at the head end of the train.

On the other hand, the curves for the "H" train show the same times (practically) for the commencement of the release for each car recorded, but it will be observed that the release curves are practically parallel; that is, the fall of cylinder pressure is at the same rate for each cylinder. And this rate is such that the 1st brake is released before the 25th brake commences to release; which, in turn, is released before the 50th commences.

Comparing now the two trains with each other, it will be seen that at the time when the 50th brake of the "K" train starts to release there is still 25 lbs. cylinder pressure on the 1st and 25th cars, and at the same time on the "H" train there is no pressure in the 1st and 25th brake cylinders while there is still 50 lbs. in the cylinder of the last car.

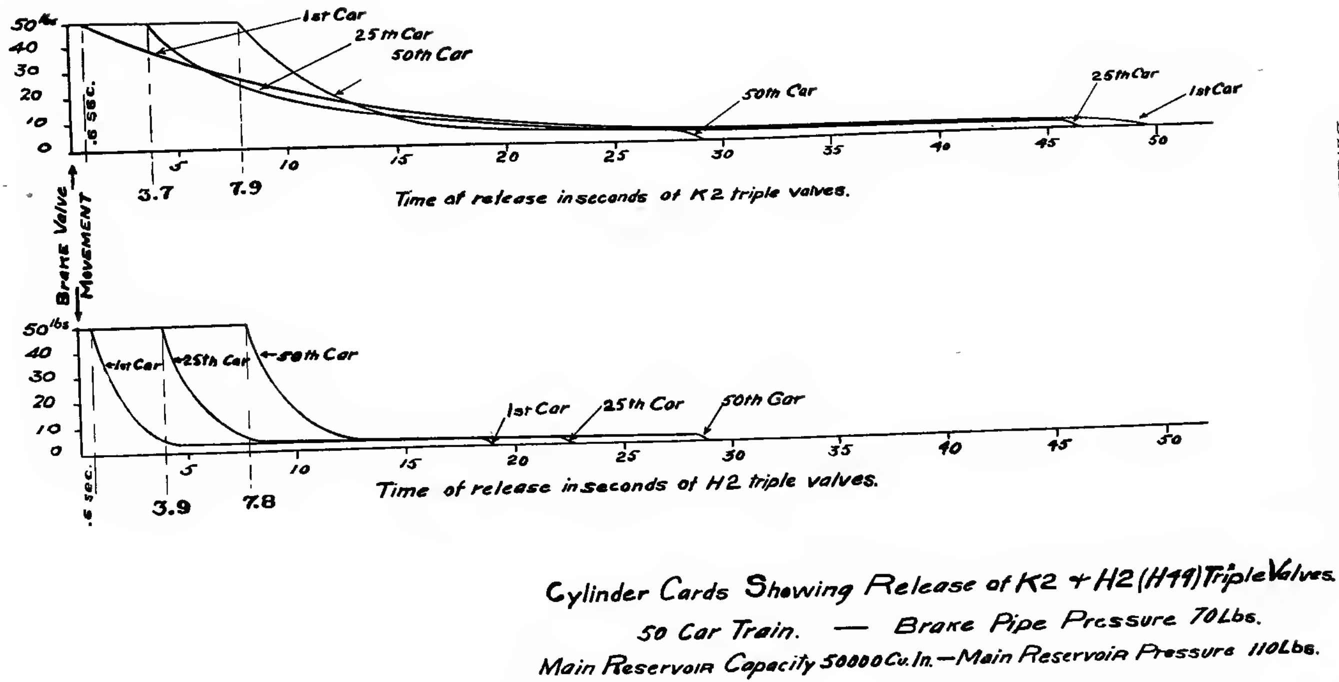


FIG. 71. RACK TEST. BRAKE CYLINDER CARDS SHOWING RELEASE CURVES OF K AND H TRIPLE VALVES; 50-CAR TRAIN.

FIGURE NO. 72.

Fig. 72 is obtained from the data of Fig. 71, when plotted to show the fall in cylinder pressure on the train as a whole. As the difference between Fig. 72 and Fig. 70 is in length of train only, a comparison of the action of the "H" and "K" valves on the shorter train similar to that made in connection with Fig. 71 may readily be made.

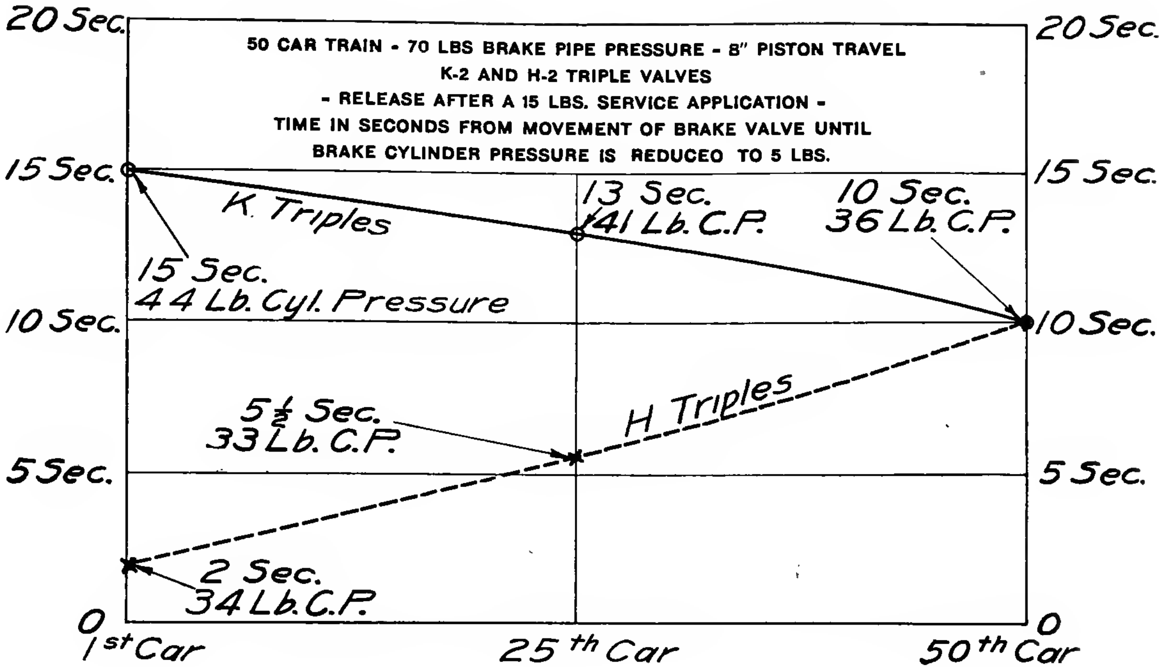


FIG. 72. RACK TEST. TIME REQUIRED TO RELEASE BRAKES ON A 50-CAR TRAIN, 2000 FEET LONG; H AND K TRIPLE VALVES.

FIGURES NOS. 73 TO 76.

Figs. 73 to 76 illustrate the rise in brake pipe pressure and fall in cylinder pressure when releasing from 5-lb., 10-lb., 15-lb., and 20-lb. reductions respectively with the "H" and "K" valves, just as Figs. 66 to 69 illustrate the fall in brake pipe pressure and rise in brake cylinder pressure when applying the brake, the cards being superimposed for ready comparison. We call your particular attention to those curves which show the rise of brake pipe pressure when the brakes are being released. You will note that it cannot be told whether the brake valve handle was in release or running position from the curves for the 25th car, to say nothing of the 50th car; note also the curves of Fig. 76, showing the release following a 20-lb. reduction. After the brake valve handle had been in release position for 15 seconds the pressure on the 1st car was 75 lbs., a rise of 25 lbs., while that on the 25th car was 58 lbs., or a rise of 8 lbs., and that of the 50th car was 56 lbs., or a rise of only 6 lbs. Moreover, by the rapid drop of the curve for the 1st car it is plainly seen when the brake valve handle was returned to running position, but there is no such indication on the 25th car or beyond. Of course, the longer the train and the greater the brake pipe leakage, the slower will be the rise of brake pipe pressure.

Uniform Recharge.

Curves might be shown to illustrate the uniform recharging of the auxiliary reservoirs on the train as a whole, but as the uniform recharge feature was incorporated primarily to prevent the overcharging of the head as compared with the rear end of the train, what has already been said concerning this feature is deemed sufficient.

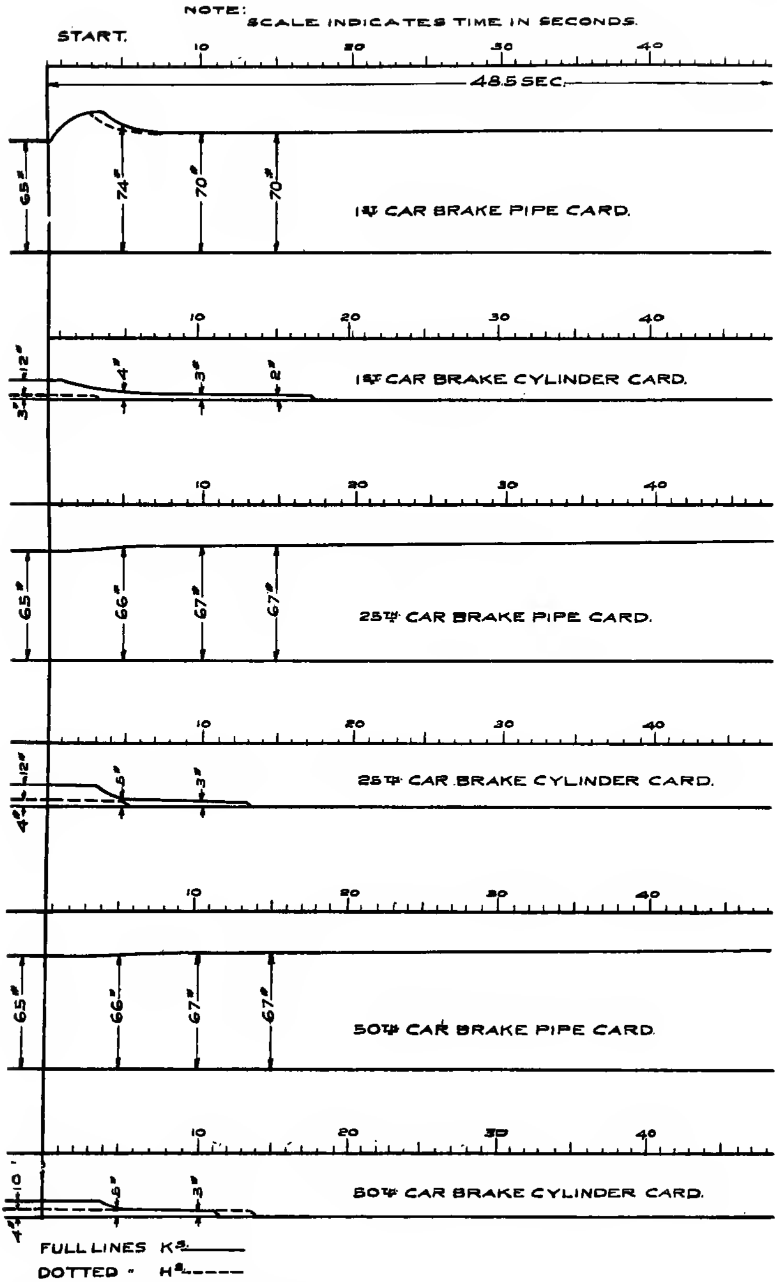


FIG. 73. RACK TEST. BRAKE PIPE AND BRAKE CYLINDER CARDS, 50-CAR TRAIN, H AND K TRIPLE VALVES. RELEASE AFTER A 5 LB. REDUCTION

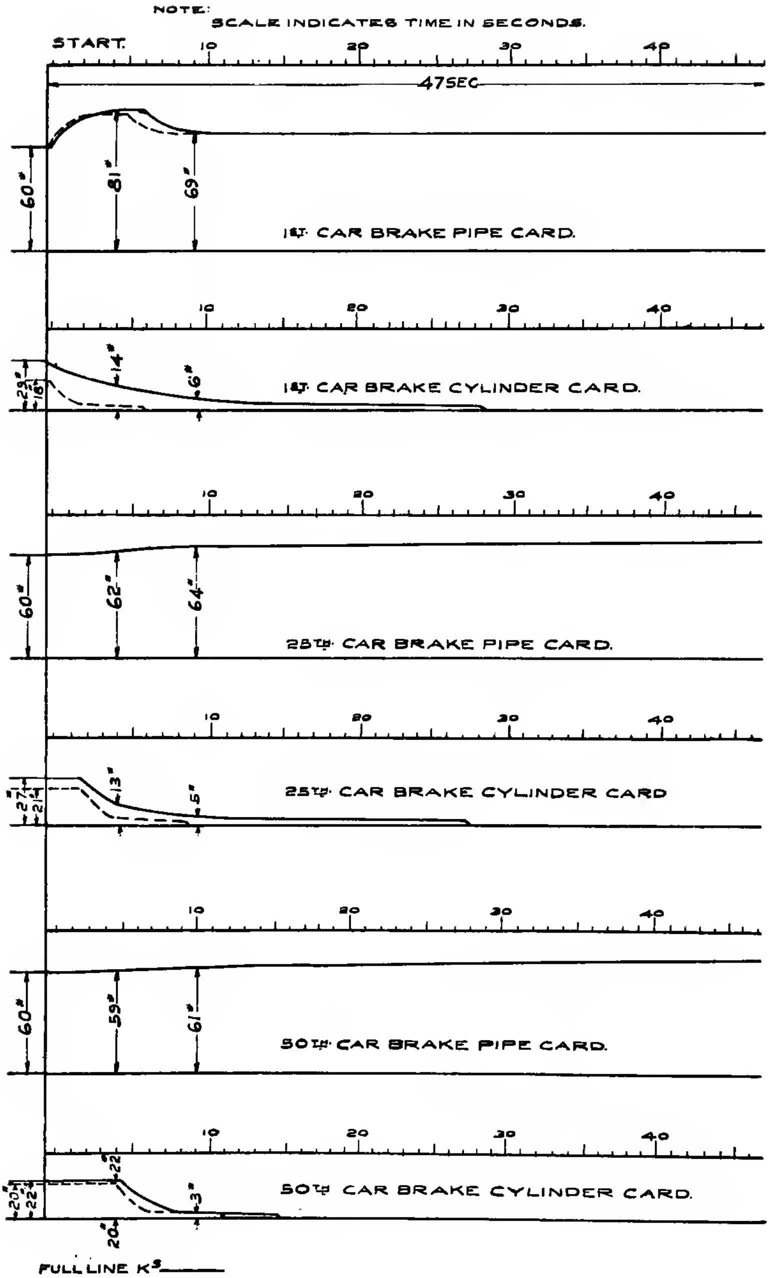


FIG. 74. RACK TEST. BRAKE PIPE AND BRAKE CYLINDER CARDS, 50-CAR TRAIN, H AND K TRIPLE VALVES. RELEASE AFTER A 10 LB. REDUCTION.

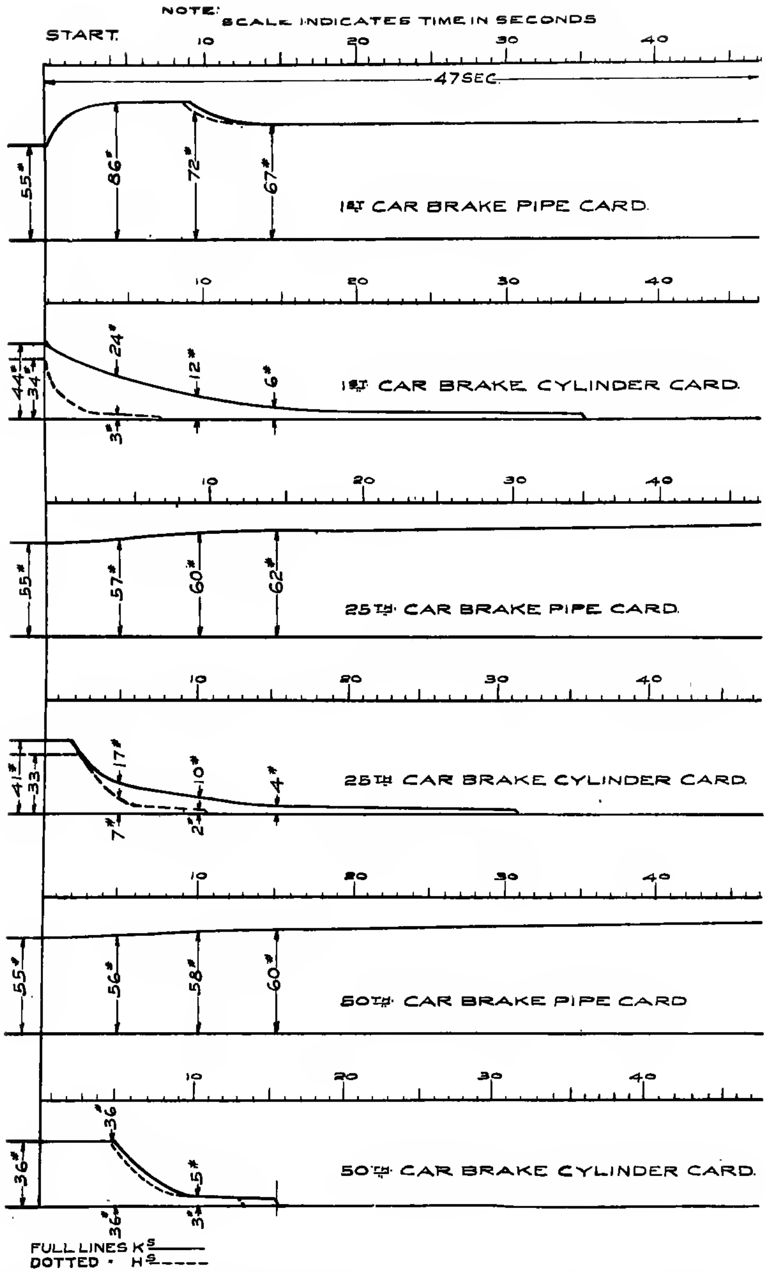


Fig. 75. Rack Test. Brake Pipe and Brake Cylinder Cards, 50-Car Train, H and K Triple Valves. Release After a 15 lb. Reduction

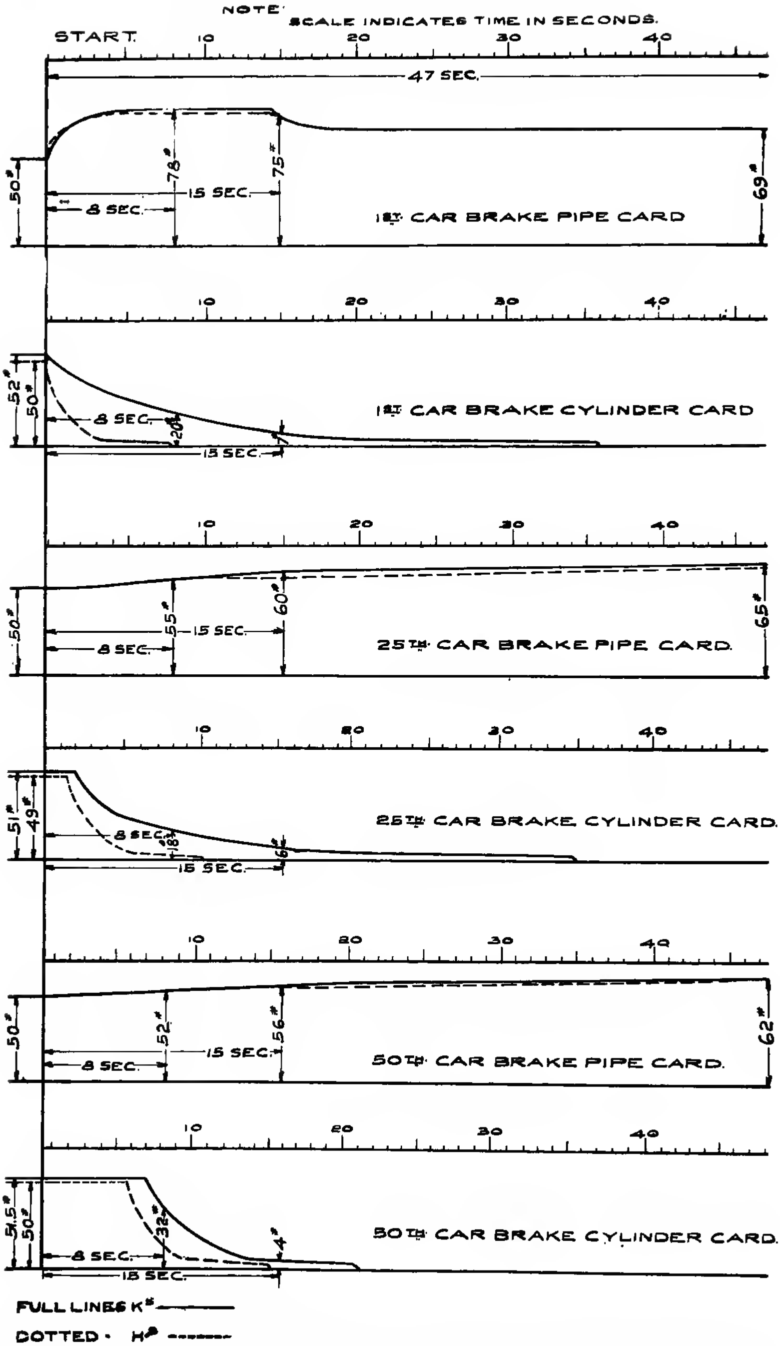


FIG. 76. RACK TEST. BRAKE PIPE AND BRAKE CYLINDER CARDS, 50-CAR TRAIN, H AND K TRIPLE VALVES. RELEASE AFTER A 20 LB. REDUCTION

FIGURE No. 77.

Emergency Application.

Fig. 77 shows brake pipe and brake cylinder cards for the 1st, 25th, and 50th cars of a 50-car train, emergency application, both "K" and "H" triple valves, and as the indicator cards were alike with both valves, the lines coincide exactly when superposed. This was to be expected, as there is no difference whatever in the quick action parts of the "H" and "K" valves.

However, the diagrams are instructive in that they show the characteristics of the fall of brake pipe pressure, the difference in time of the application of the first and last brake, and the cylinder pressure obtained. Also, when compared with the curves of Fig. 69, a striking contrast is at once apparent between the service and emergency applications of the brakes. For instance, 48 seconds were required to obtain 50 lbs. cylinder pressure on the 50th car with a service application, while 60 lbs. cylinder pressure was obtained on the 50th car with an emergency application in three seconds.

Service Results.

It would naturally be concluded that the new features of operation shown to exist in the "K" triple valve would be productive of remarkable results and a great improvement in the controlling and operating of trains under the present severe conditions. That the expected was realized in this case has been demonstrated many times, and the curves and data which follow have been taken from the records of tests made by various railroads for the purpose of demonstrating the existence of the improvements and the benefits to be derived therefrom in service, such as increase in tonnage, greater factors of safety, especially on mountain grades, and general betterment in train handling.

As the operation of the brake in service is no different in kind from what has already been treated in more or less detail, it will only be necessary to discuss the curves which follow with reference to the actual movement of trains, in which the factors of resistance, slack, and the relation of the different cars to each other as to differences in braking power, etc., must be considered.

Standing Tests.

The standing tests referred to on the pages immediately following were made on an 80-car train, ready for service, which train was subsequently used for the running tests to be described later, corresponding tests being made with the train equipped first with "H" valves, then with "K" valves, and then with "H" and "K" valves mixed in the train.

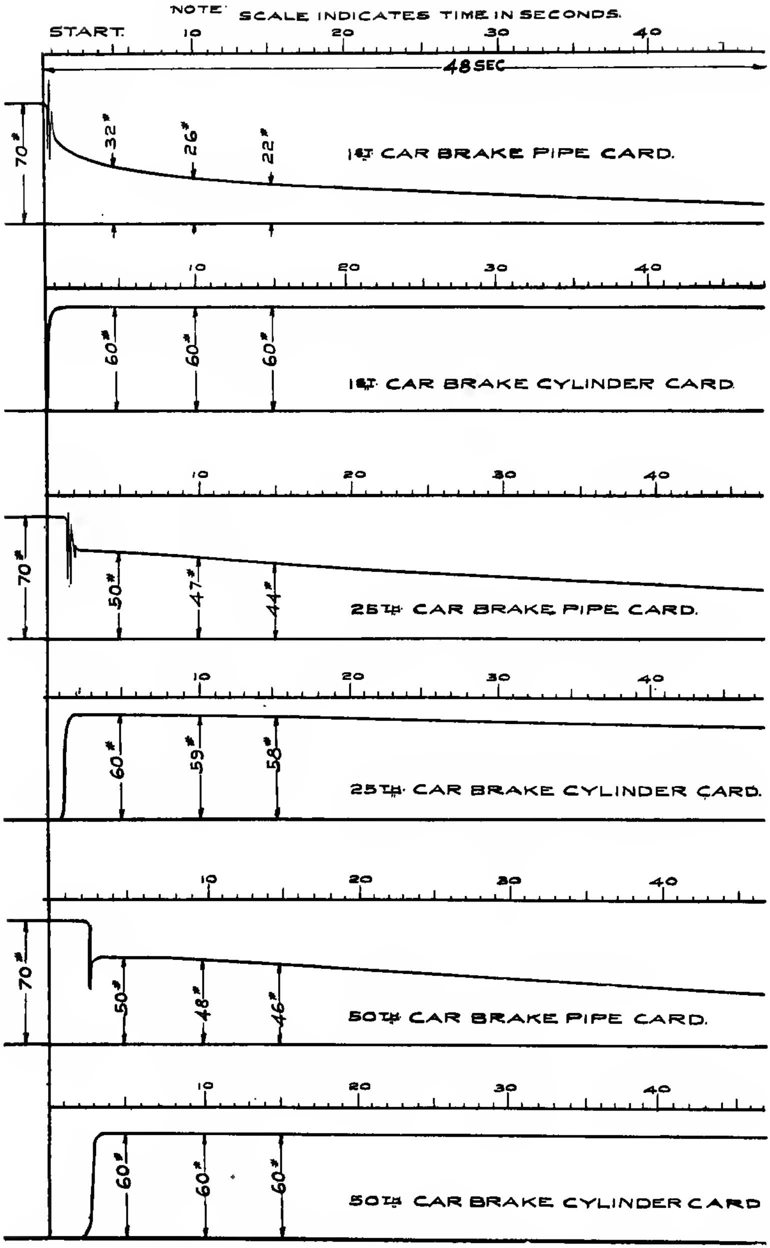


FIG. 77. RACK TEST. BRAKE PIPE AND BRAKE CYLINDER CARDS, 50-CAR TRAIN, H AND K TRIPLE VALVES. EMERGENCY APPLICATION.

FIGURES NOS. 78 TO 81.

Figs. 78 to 81 illustrate the operation of the brakes when using the different types of triple valves on an 80-car train, making 5-lb., 10-lb., 15-lb., and 20-lb. reductions respectively.

In Fig. 78 it is important to note that only the first 33 brakes applied on a 5-lb. reduction when using the "H" valves, but that all applied with "K" valves or "H" and "K" valves mixed.

In the three remaining tests of this series all brakes applied in each case, and two points should be especially observed: 1st, that the brakes were applied by the "K" valves in less than one-half the time required with the "H" valves; and 2nd, that when the valves were mixed in the train the operation of the brakes was then more nearly that of the "K" train than that of the "H" train; in other words, the time of application of the brakes was reduced by about 30 per cent.

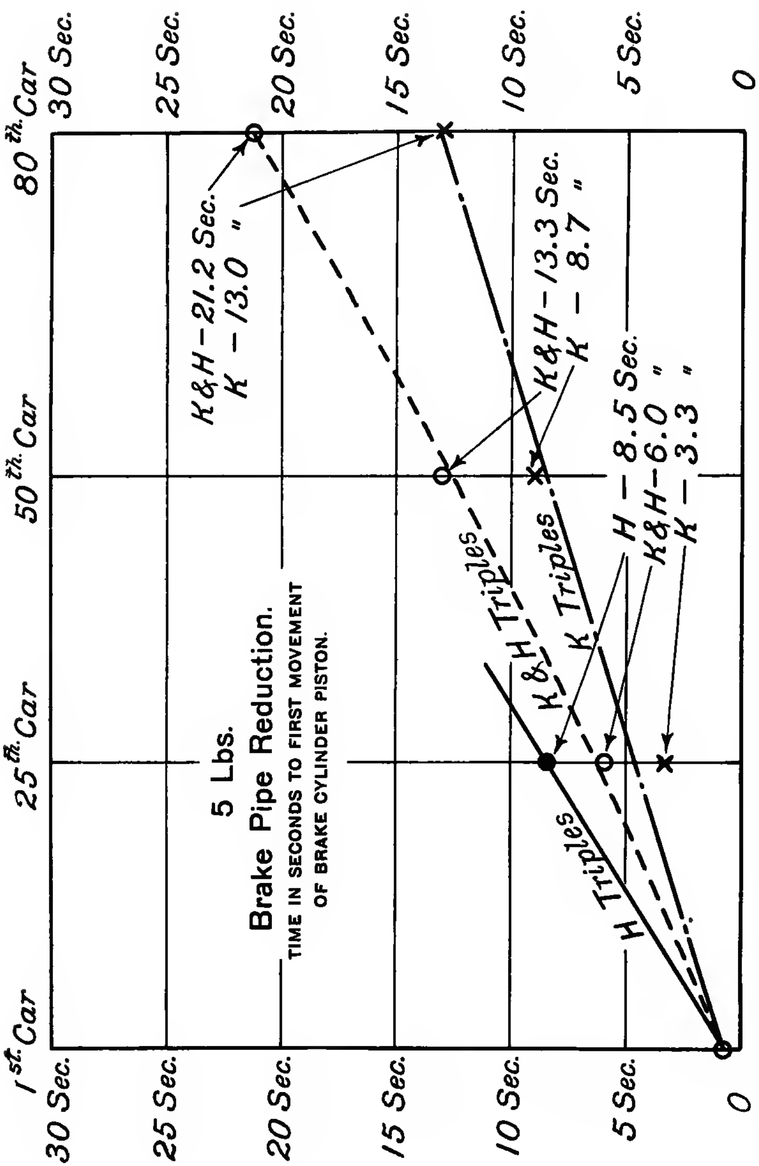


FIG. 78. STANDING TEST. 80-CAR TRAIN. TIME TO MOVE BRAKE PISTONS WITH H, K AND MIXED H AND K TRIPLE VALVES. 5 LB. REDUCTION.

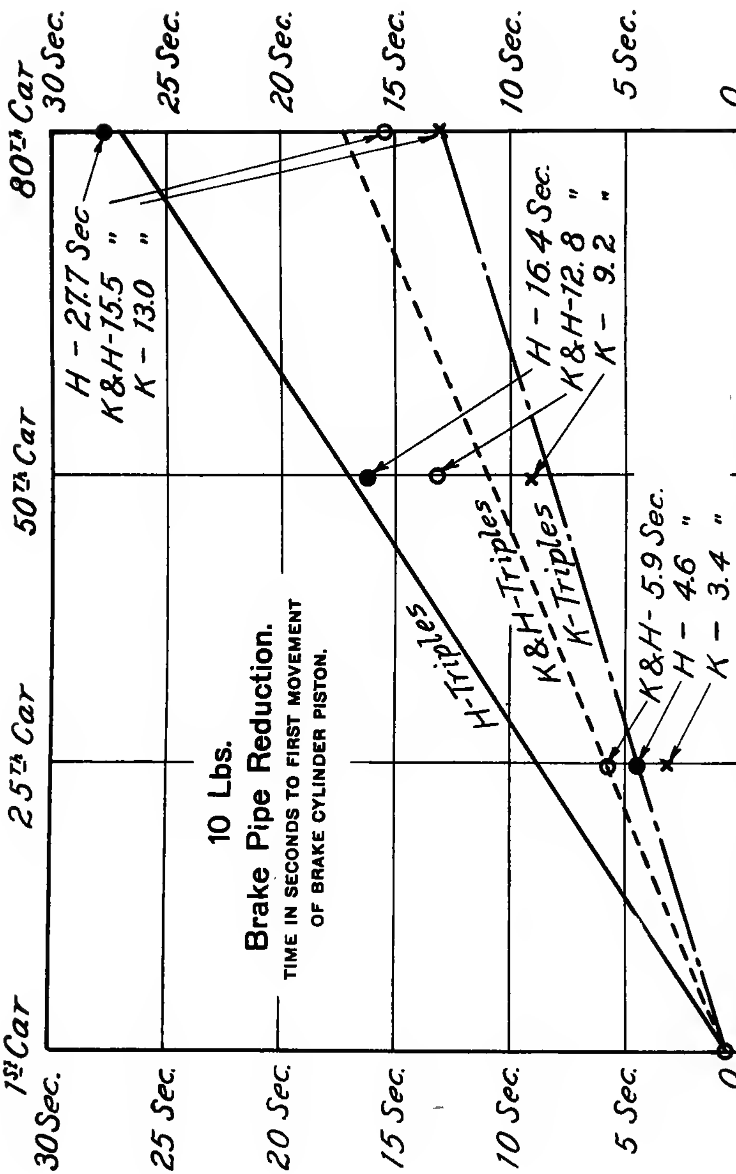


FIG. 79. STANDING TEST. 80-CAR TRAIN. TIME TO MOVE BRAKE PISTONS WITH H, K AND MIXED H AND K TRIPLE VALVES. 10 LB. REDUCTION.

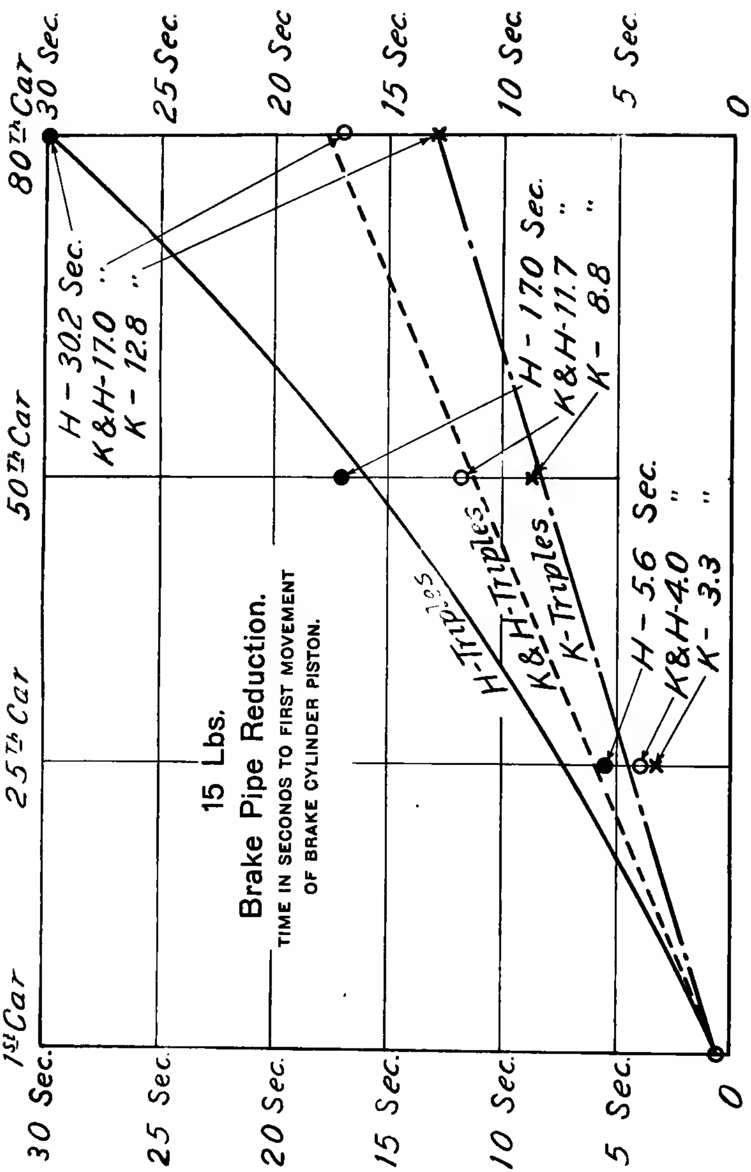


FIG. 80. STANDING TEST. 80-CAR TRAIN. TIME TO MOVE BRAKE PISTONS WITH H, K AND MIXED H AND K TRIPLE VALVES. 15 LB. REDUCTION.

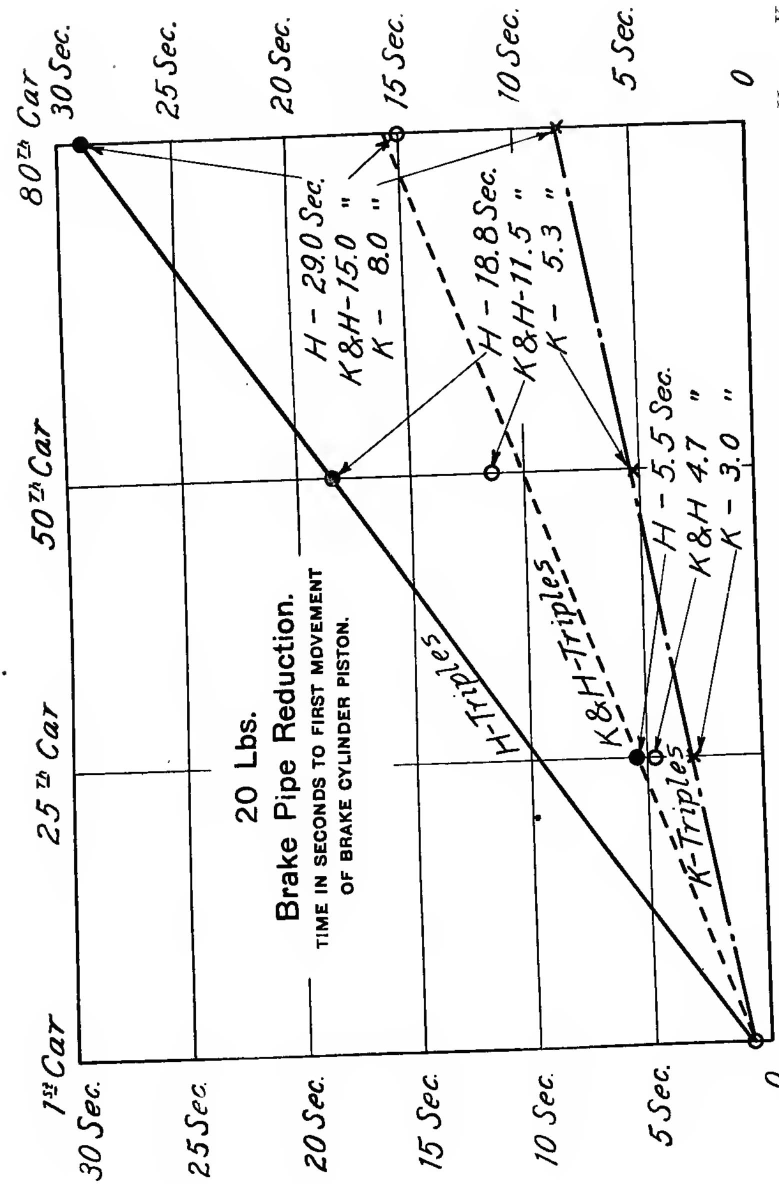


Fig. 81. Standing Test. 80-Car Train. Time to Move Brake Pistons with H, K and Mixed H and K Triple Valves. 20 lb. Reduction.

FIGURES NOS. 82 TO 85.

While Figs. 78 to 81 have shown only the comparative promptness of response of the triple valves, Figs. 82 to 85 show the comparative times required to obtain effective braking pressures with the different types of valves under conditions similar to those for the preceding curves.

From Fig. 82 it will be seen that for a 5-pound reduction no effective braking power was produced beyond about the 10th car with the "H" valves, while with the "K" valves alone, or "K" and "H" valves mixed, braking power was produced throughout the entire train. The remaining three charts of this series are of interest in showing that with the "K" valves, or "H" and "K" valves mixed, the brakes on long trains can be applied on the rear before the slack can run in and before the brakes can be applied heavily on the head end.

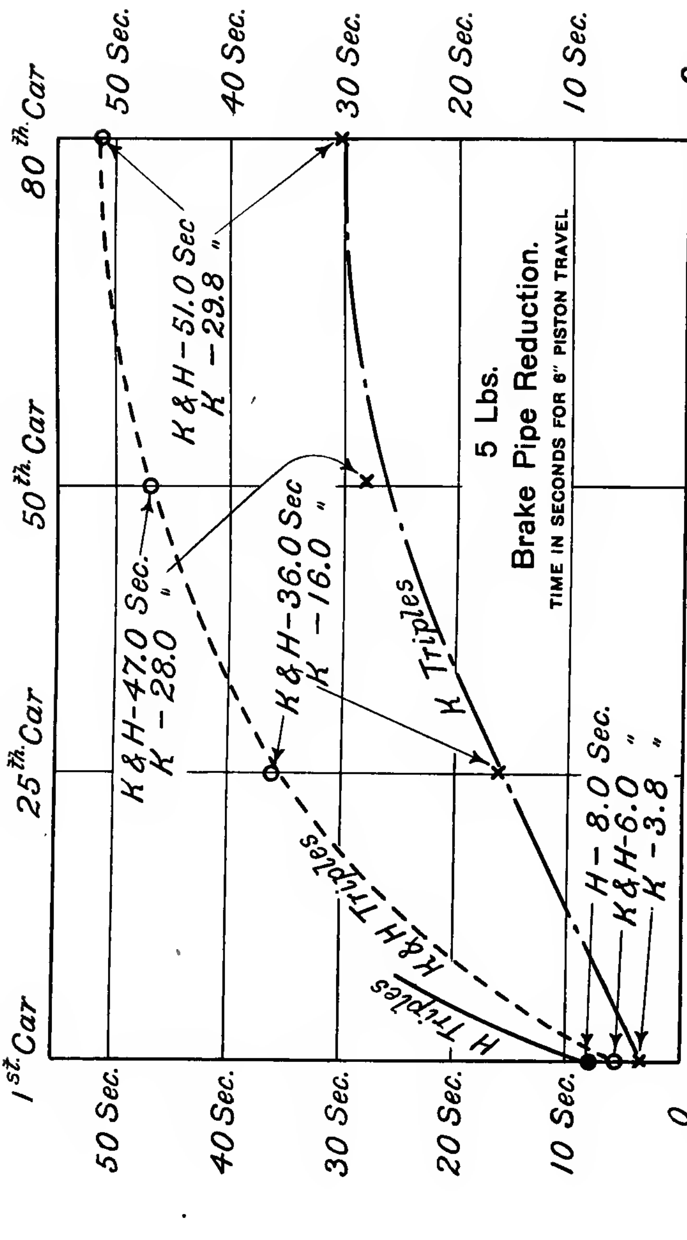


FIG. 82. STANDING TEST. 80-CAR TRAIN. TIME TO OBTAIN EFFECTIVE BRAKING PRESSURE WITH H, K AND MIXED H AND K TRIPLE VALVES. 5-LB. REDUCTION.

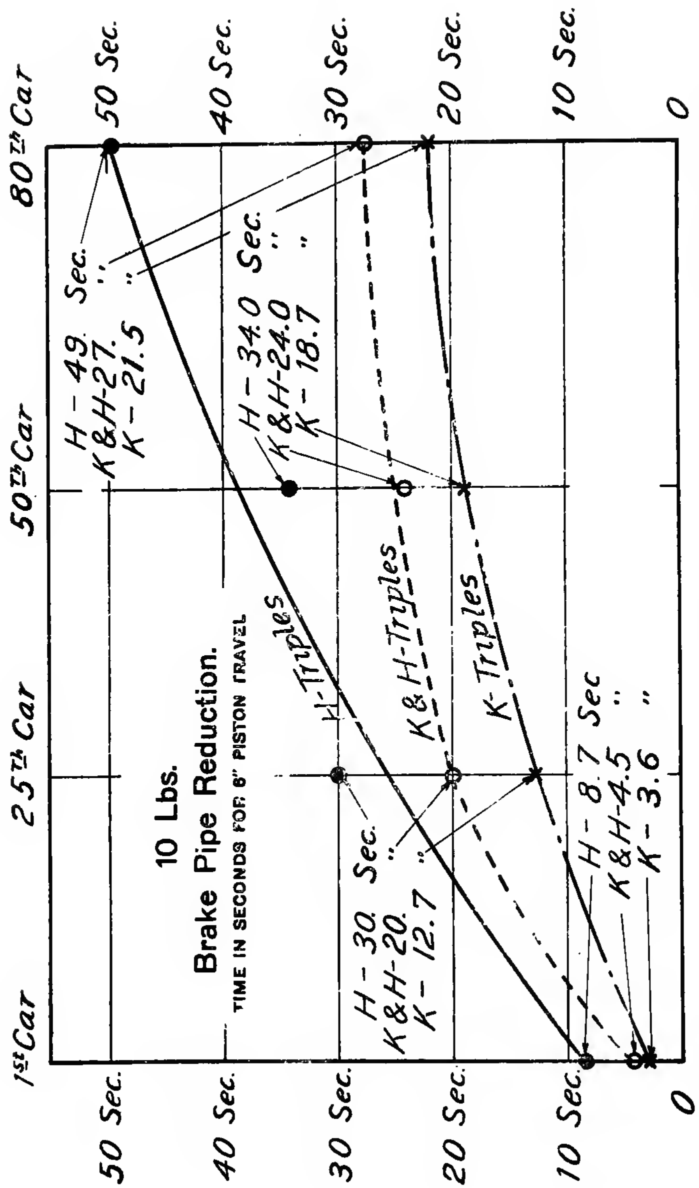


FIG. 83. STANDING TEST. 80-CAR TRAIN. TIME TO OBTAIN EFFECTIVE BRAKING PRESSURE WITH H, K AND MIXED H AND K TRIPLE VALVES. 10-LB. REDUCTION.

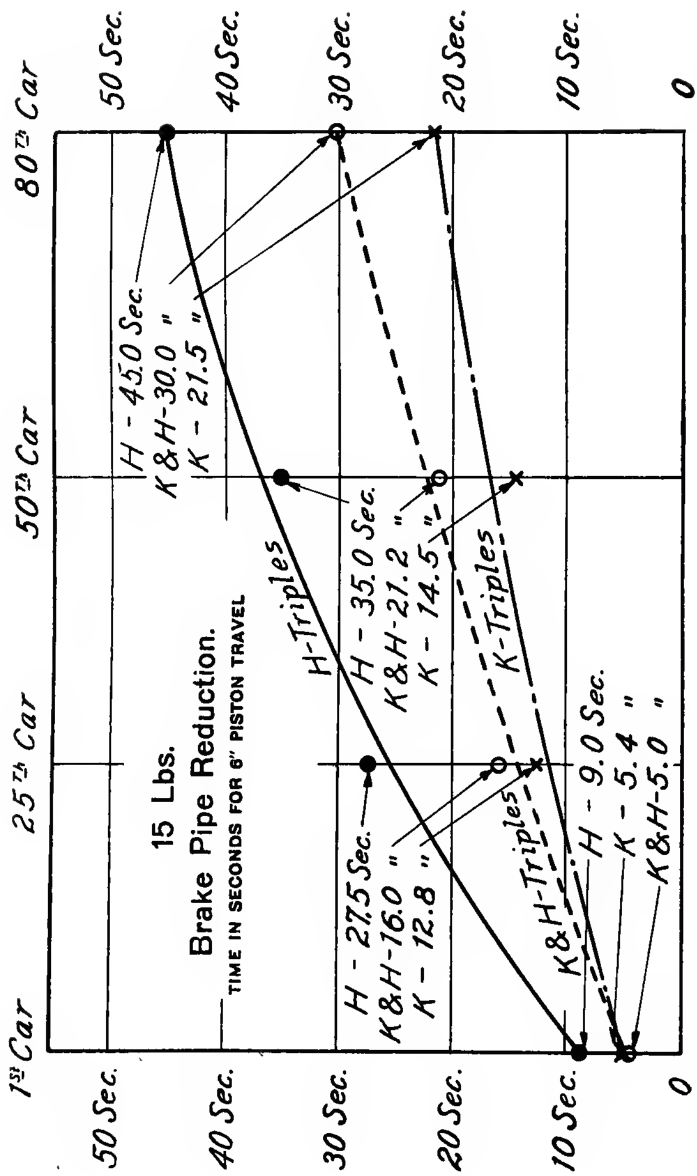


FIG. 84. STANDING TEST. 80-CAR TRAIN. TIME TO OBTAIN EFFECTIVE BRAKING PRESSURE WITH H, K AND MIXED H AND K TRIPLE VALVES. 15-LB. REDUCTION.

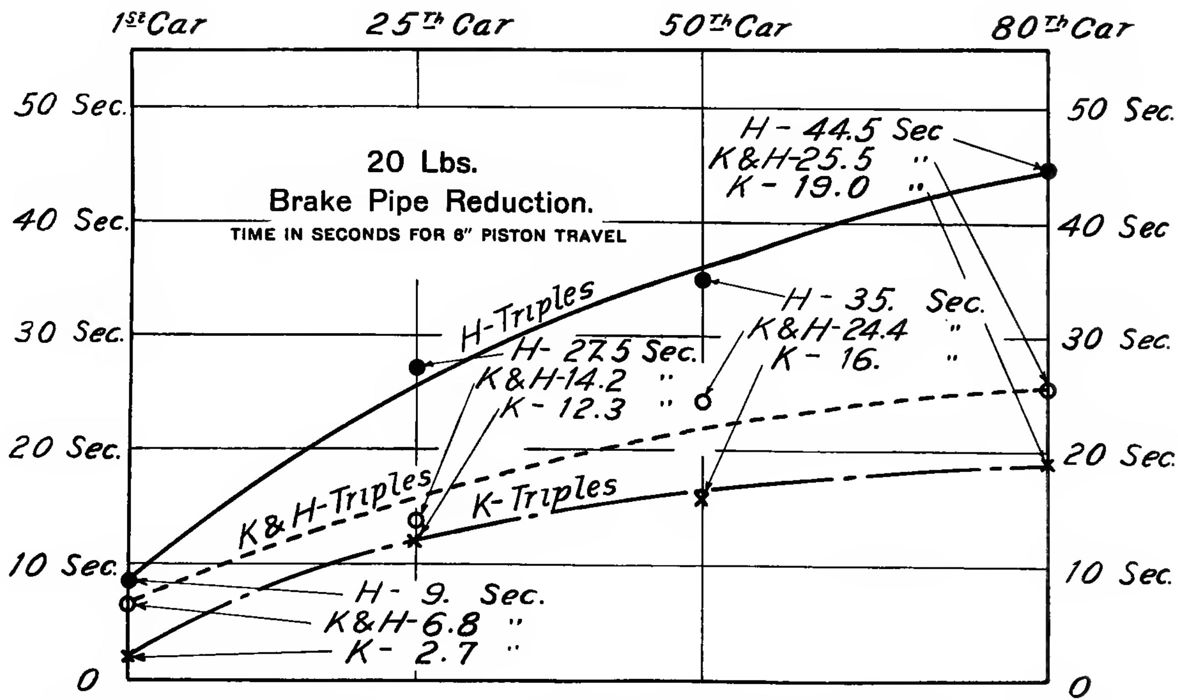


FIG. 85. STANDING TEST. 80-CAR TRAIN. TIME TO OBTAIN EFFECTIVE BRAKING PRESSURE WITH H, K AND MIXED H AND K TRIPLE VALVES. 20-LB. REDUCTION.

FIGURE NO. 86.

Fig. 86 shows the number of brakes that applied, the brake cylinder pressures obtained, and the times in which these pressures were obtained for 5-lb., 10-lb., and 15-lb. reductions. These diagrams illustrate very graphically the effectiveness of the brake applications with the different valves, both as to the amount and the distribution of the cylinder pressure throughout the train. The work done is, of course, proportional to the shaded areas of the diagrams, and its effect on the train is, therefore, directly as this area, and inversely as the time of obtaining the cylinder pressure with the different valves.

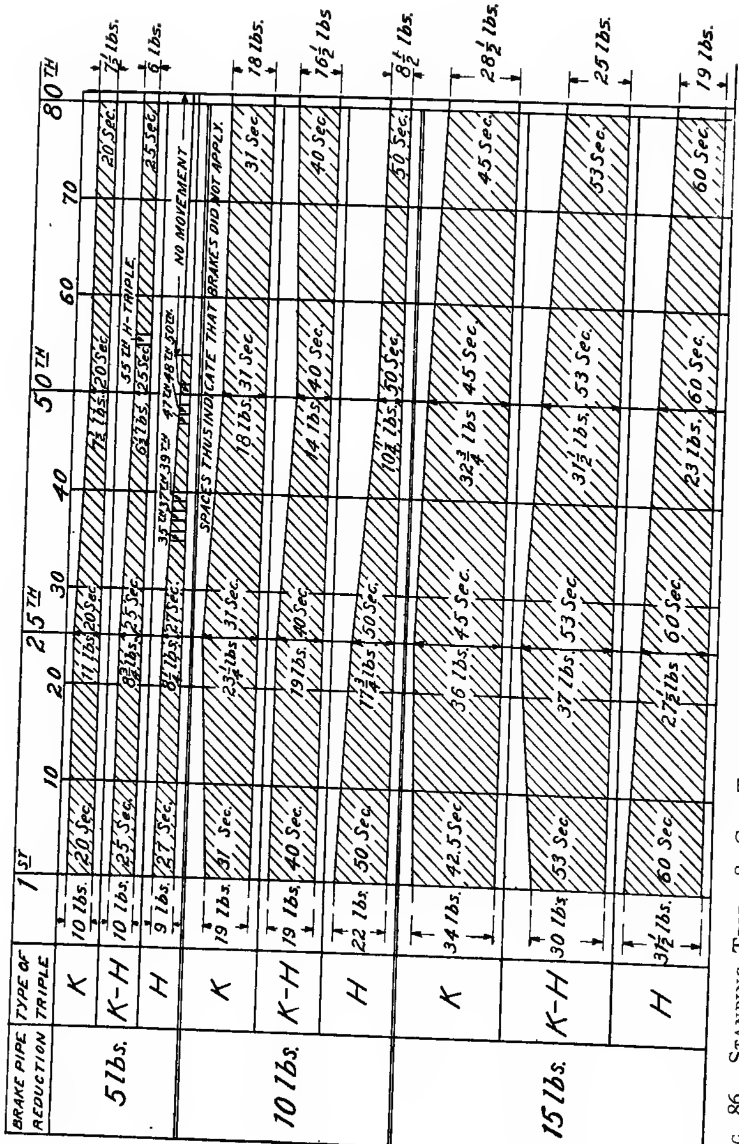


FIG. 86. STANDING TEST. 80-CAR TRAIN. H, K AND MIXED H AND K TRIPLE VALVES. APPLICATION OF BRAKES, CYLINDER PRESSURE OBTAINED AND TIMES FOR TRAIN AS A WHOLE. 5 LB., 10 LB. AND 15 LB. REDUCTION.

Figure No. 87.

Fig. 87 illustrates the uniformity of release obtained with the "K" valves and the absence of all uniformity in releasing with the "H" valves. Moreover, it shows clearly why a release of the brakes at slow speeds can safely be permitted with the "K" valves and conversely why it is impossible to release at slow speeds with the "H" valves without danger of break-in-two or shifting of lading. For instance, the release of all the brakes on the "K" train was practically simultaneous, being accomplished with only 1.7 seconds variation in the times of releasing the different brakes, while with the "H" valves, the brake on the first car was released 35½ seconds before that on the last car.

Running Tests.

The running tests which followed the above series of standing tests were undertaken to demonstrate four things.

1st. That brakes could be applied in service without shock or break-in-two under conditions which, with the older type, would produce a break-in-two or shifting of the lading.

2nd. That brakes could be released when running at low speeds with impunity, under conditions which, with the old equipment, would inevitably result in damaging shocks or break-in-twos.

3rd. That much shorter stops could be made for a given reduction, and that the same stop could be made with a much less reduction than when the older equipment is used.

4th. That much greater tonnage could be handled down grades with even greater safety than has heretofore been possible, in addition to greatly improving the general control of the train, thereby minimizing to a considerable degree the effect of the personal equation in this exacting and dangerous work.

First, as to the effect of the applications and releases with long trains. It is impossible, of course, to show by means of curves the freedom from shocks and break-in-twos insured by the new equipment. Therefore, to substantiate what has already been said in this connection, it will be sufficient to refer to certain tests which have fully demonstrated the efficiency of the improved brake in these particulars.

These tests were made with very long trains at different speeds, with different reductions with both types of equipment, and it was found that neither shocks nor break-in-twos would result with the new equipment under conditions which proved very damaging, both to cars and lading with the old; and releases were made without shock of any kind with the new equipment under conditions which, with the old equipment, resulted in breaking the train in from two to half a dozen pieces, generally four, two at the head, and two at the rear.

For example, one of the tests made was with a train of 80 of the heaviest modern steel cars, equipped for the demonstration first with one and then with the other type of valve. At speeds varying between 15 and 30 m. p. h., heavy applications were made and always without shock or

break-in-two with the new equipment, and generally with heavy shocks and occasional break-in-twos with the old. After the train had been slowed down to a speed of 8 or 10 m. p. h., a release was made and the engine throttle opened. This invariably resulted in a break-in-two with the old equipment, while with the new equipment the train could be kept moving without damage.

Again, a demonstration was made with 50 of the cars, 25 of them loaded and 25 empty, loads ahead, to note the results in service of the uniform releasing of the brakes with the "K" triple valves.

The loads were placed ahead to magnify the effect of slack running out as brakes released on the front cars. These loaded cars, of course, had the lowest per cent. of braking effort; in other words, the train was made up to represent the worst possible conditions.

The train was accelerated to 21.4 m. p. h. when a heavy brake application was made and held until the speed had been reduced to 7.25 m. p. h., when the brakes were released and the engineer applied steam *with full throttle,* the engine then exerting approximately 45,000 lbs. tractive effort. This test was, as a matter of fact, a deliberate attempt to break the train in two.

The result, as shown by the chronograph records of a dynamometer car between the load and empties, was simply a steady increase in draw-ba: pull, no jerk, and train was put under headway without stopping and *without any internal shocks whatever.*

This demonstration illustrates the beneficial effect of the uniform release feature of the "K" triple valve, which, in its far-reaching importance to the operating department, is almost, if not quite, equal in value to the quick service feature in freight train handling.

In this connection, it will be of interest to quote one or two statements from a large number of copies of reports from railroad men, showing how the new equipment is working out in every-day service.

A train, consisting of 60 cars, 30 ahead having the new equipment, and the 30 behind them having the old equipment, was being taken over a certain road. "On request the engineer slowed down and released at low speed at a point where the rear of the train was on a curve and the head end on a tangent. He was so sure of this being a point where, with the brakes he was accustomed to, this operation would result in a break-in-two, that he would consent to make the release only under official assurance that he would be relieved of all responsibility for damage and any delay to a passenger train with which he had a 'meet order.' The results were all that could possibly be desired, as there were absolutely no shocks to any portion of the train, and the time when the slack was fully out was perceived only by the most careful observation."

"A train, consisting of 70 cars, with a coach on the rear, was made up for a run to Chicago. While the train was running at about 25 m. p. h. a 10-lb. brake pipe reduction was made, and when completed and the speed of the train reduced to between 8 and 10 m. p. h., the brake valve handle was placed in release position and the engine throttle gradually opened.

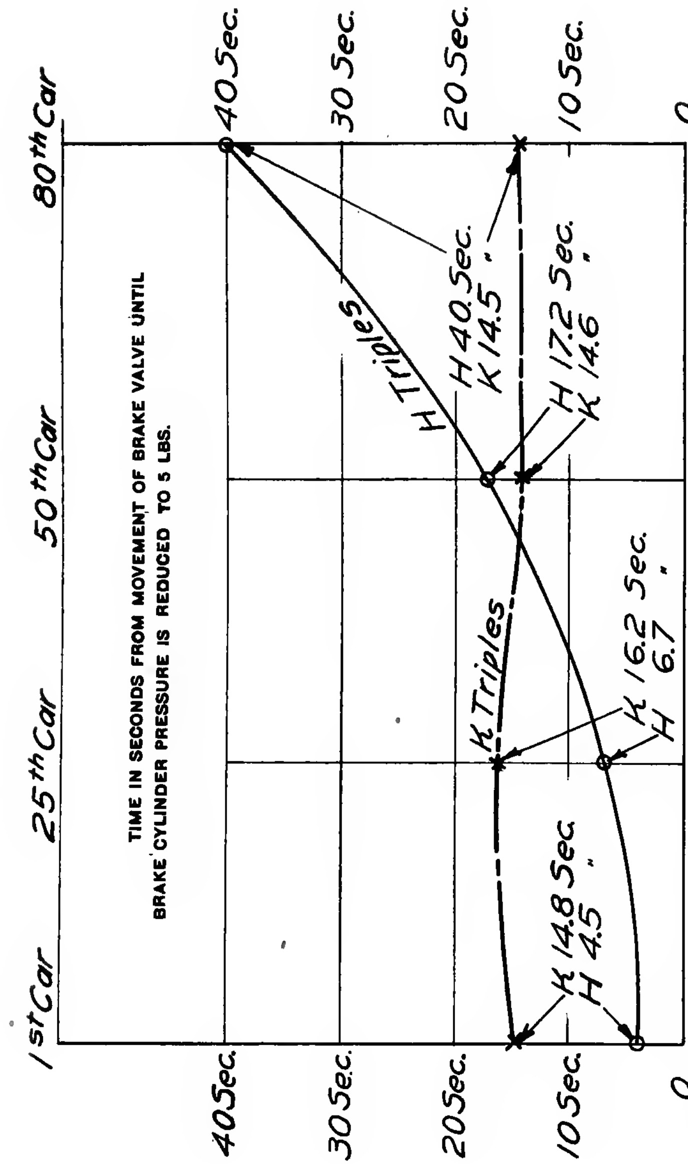


FIG. 87. STANDING TEST. 80-CAR TRAIN. TIME REQUIRED TO RELEASE BRAKES ON AN 80-CAR TRAIN. H AND K TRIPLE VALVES.

The brakes were still retarding the engine, so the throttle was eased off a little, when the engine was apparently given a backward pull by the draft springs, though it was not in the form of a shock. The speed was reduced to about 3 or 4 m. p. h., but the train was kept in motion without being parted, and again there were no apparent shocks in the coach on the rear."

"The release of the brakes on long trains at slow speeds with the ordinary equipment is very damaging to cars and contents, and the opening of the throttle before the brakes have been fully released and the slack adjusted is the height of folly. In view of the above, I believe we gave the 'K' triple valve a hard test."

FIGURES NOS. 88 TO 91.

Coming now to a comparison of actual stops made with the two equipments, Figs. 88 to 91 show stop curves for trains of all "K" valves, all "H" valves, and mixed "H" and "K" valves, for different speeds and 5-lb., 10-lb., 15-lb., and 20-lb. brake pipe reductions. It will be seen, for example, from Fig. 88 that from a speed of 35 m. p. h. a 5-lb. reduction stopped the train equipped with "H" valves in a distance of 4.227 feet. while with the "K" valve the stop was made in a distance of 1,750 feet, and what is perhaps most remarkable is that with the train equipped with half "H" and half "K" valves, alternating, the stop was made in a little less than 2,000 feet, or almost as good as for the train when equipped with "K" valves alone.

The reason for these differences is plainly apparent from an examination of Fig. 82.

The remaining curves of the series, Figs. 89 to 91, show the same characteristics, but, of course, with a less gain for the "K" valves as the reduction approaches the maximum, for the reason that, at the speeds developed, the stop is made with the "K" valve before the full cylinder pressure can be obtained. As regards a comparison of actual stops made from various speeds with the different types of valves, the curves furnish so complete and clear a contrast that special comment is not required.

It will be readily seen from these curves, however, that trains can be controlled with light applications and the improved equipment in distances that have heretofore (with the older equipment) required heavy applications, and as the end desired with service applications is smoothness and saving of time, the use of the "K" triple valves avoids the necessity for heavy or emergency applications, *and the saving in damage to lading en route is beyond estimate.* For, where the same stopping distance results, in one case with 1/3 the brake pipe reduction required in the other, it is evident that this can only be brought about by a great uniformity of braking power, and in the time in which it is obtained, on the various cars in the train, which necessarily means a minimum of shock, both during application and release.

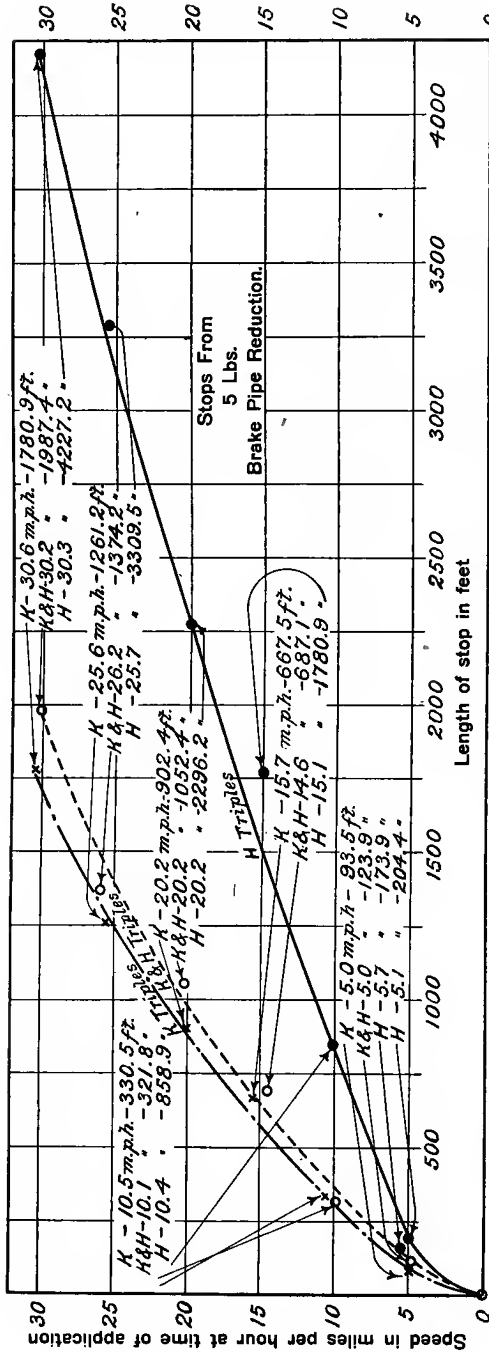


FIG. 88. RUNNING TEST. 80-CAR TRAIN. TIME REQUIRED TO STOP FROM DIFFERENT SPEEDS WITH H, K AND MIXED H AND K TRIPLE VALVES. 5-LB. REDUCTION.

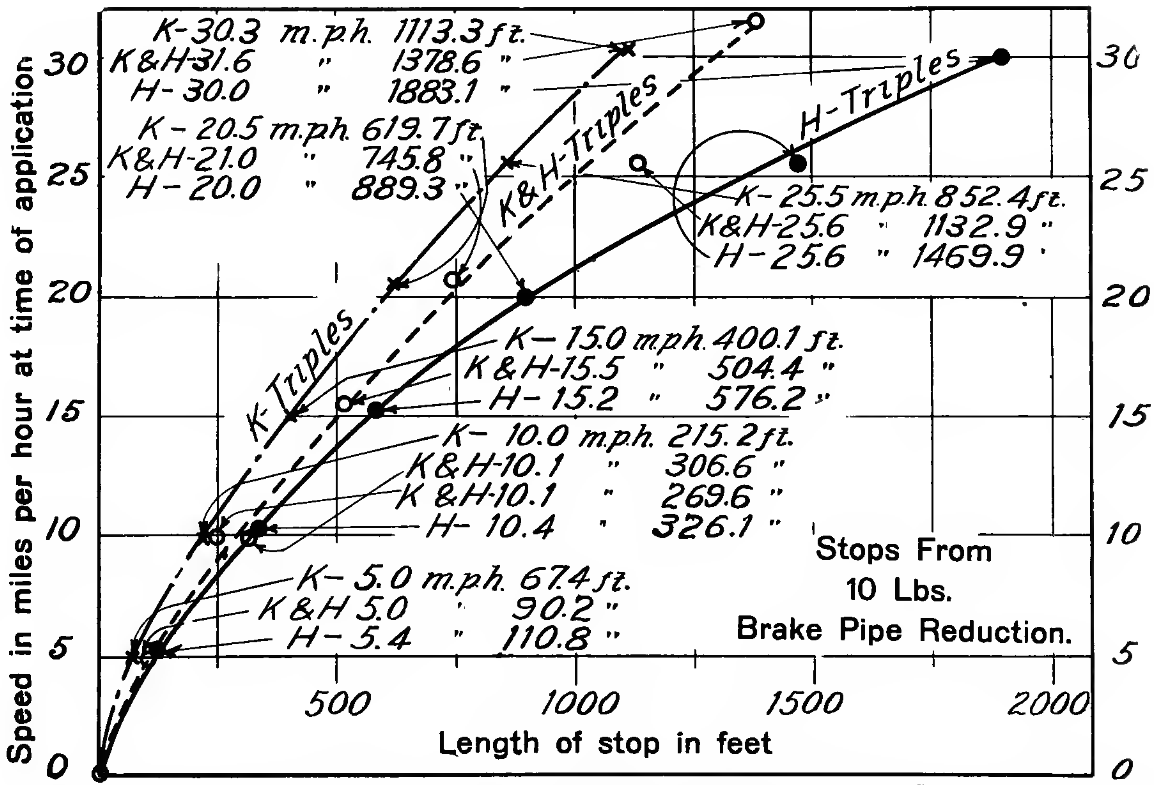


FIG. 89. RUNNING TEST. 80-CAR TRAIN. TIME REQUIRED TO STOP FROM DIFFERENT SPEEDS WITH H, K AND MIXED H AND K TRIPLE VALVES. 10 LB. REDUCTION.

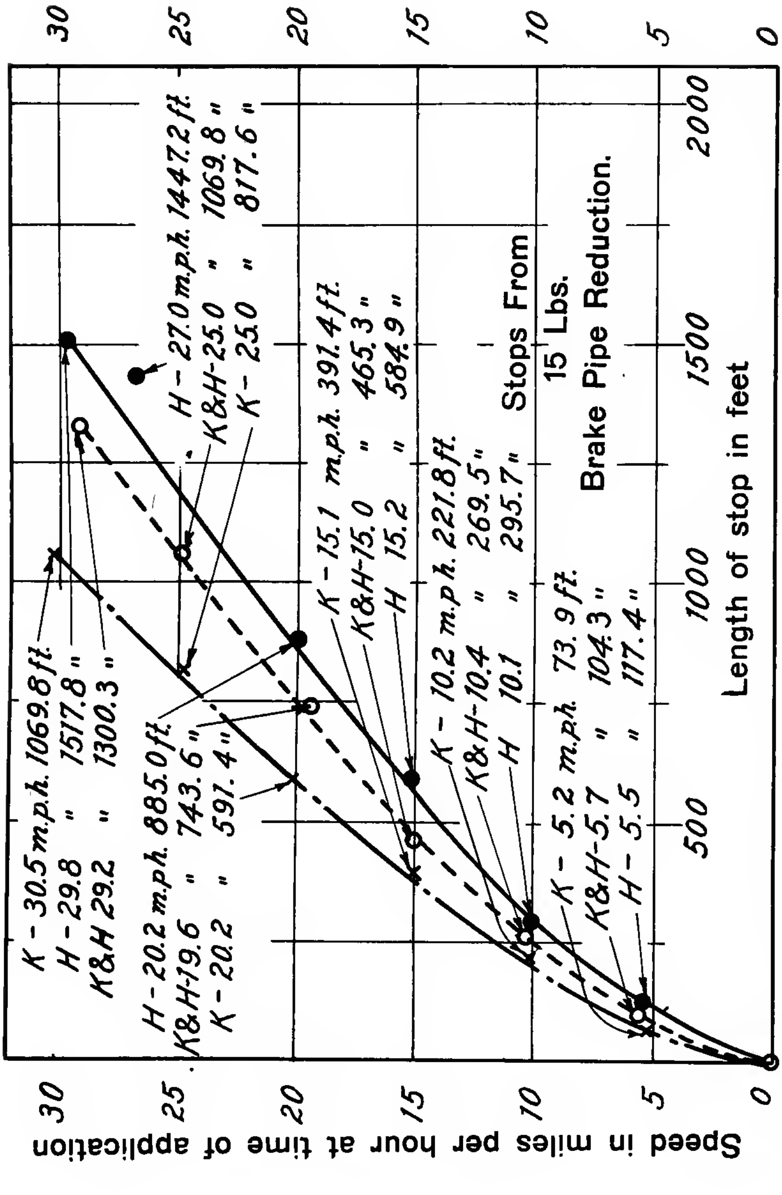


FIG. 90. RUNNING TEST. 80-CAR TRAIN. TIME REQUIRED TO STOP FROM DIFFERENT SPEEDS WITH H, K AND MIXED H AND K TRIPLE VALVES. 15 LB. REDUCTION.

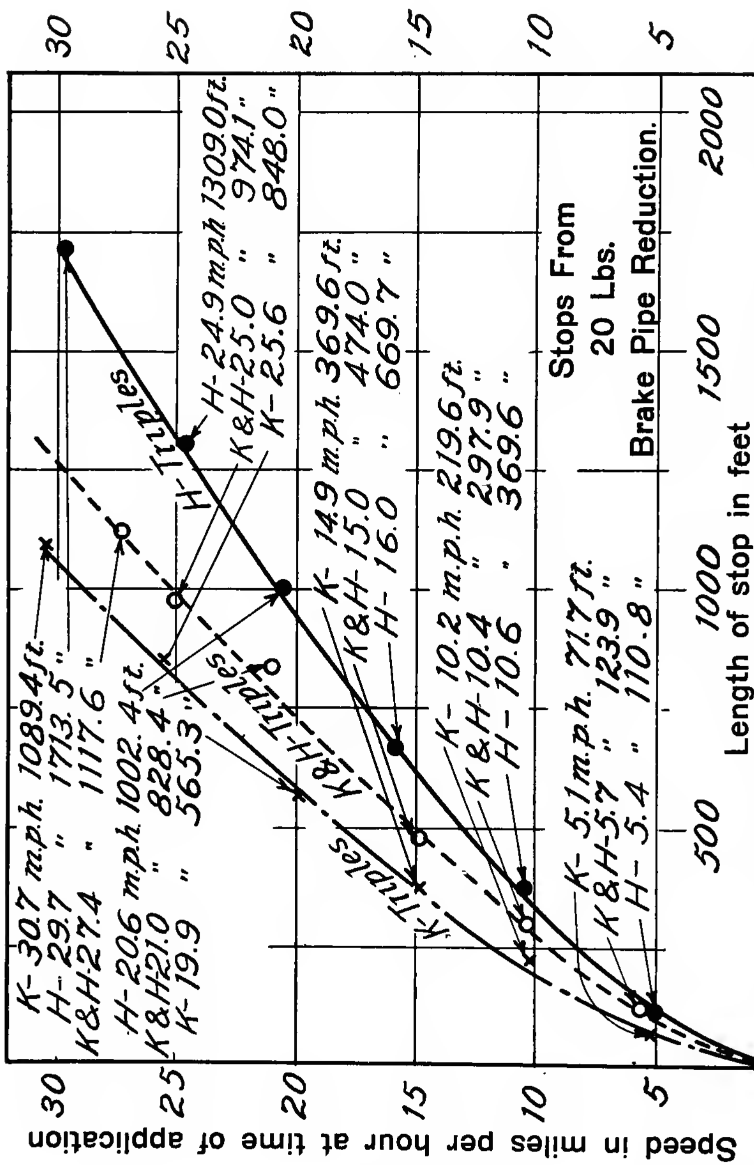


FIG. 91. RUNNING TEST. 80-CAR TRAIN. TIME REQUIRED TO STOP FROM DIFFERENT SPEEDS WITH H, K AND MIXED H AND K TRIPLE VALVES. 20 LB. REDUCTION.

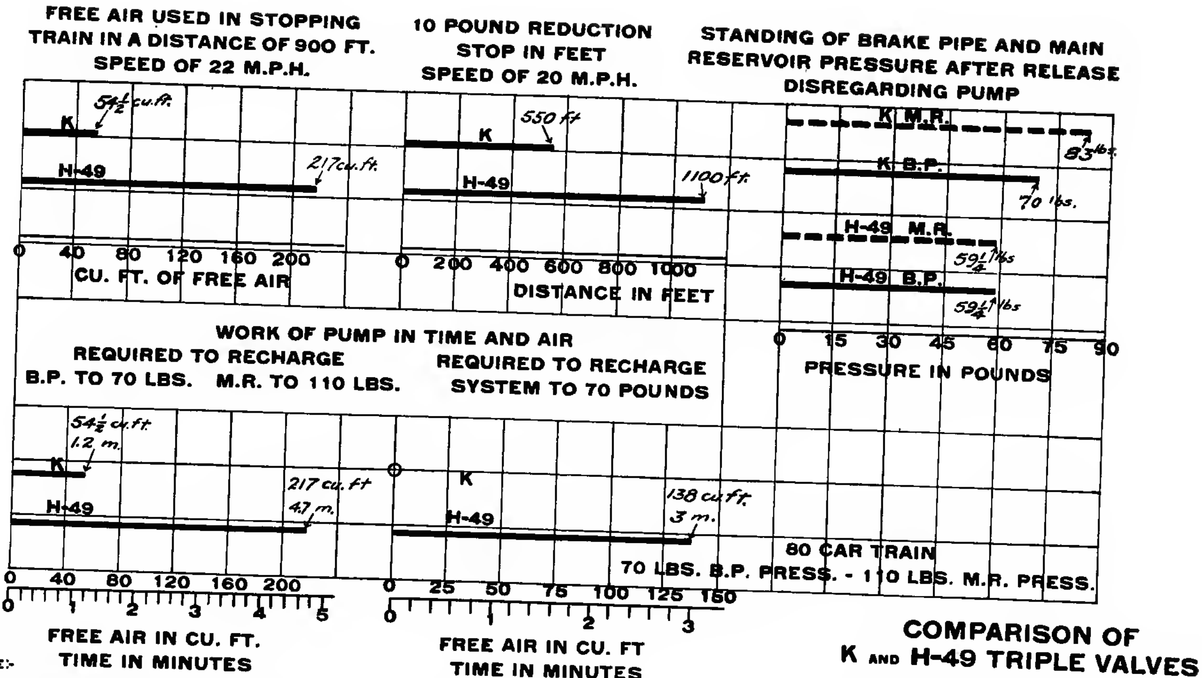
FIGURE NO. 92.

Fig. 92 illustrates graphically the difference in air consumption required for equal stops with the new and old equipment, also the difference in time required to obtain the air necessary to recharge the train, after the brake application, to the original pressure carried.

The middle diagram of the upper three shows that for a 10-lb. brake pipe reduction (in other words, using the same amount of air), with each type of triple valve under the conditions of this test, that the stop is made with the "K" valves in half the distance run with the "H" valves. This shows how much the stop can be shortened, or the train control improved for the same consumption by using the type "K" valves.

The remainder of the diagrams of Fig. 92 are plotted from the records of a 900-ft. stop with each type of valve. This stop was made with only a 5-lb. reduction with the "K" valves, while it required a 20-lb. reduction with the "H" valves to stop in this distance, the air consumption being respectively 54½ cu. ft. and 217 cu. ft., as shown by the left-hand of the upper diagram. The effect of this upon the recharge train is seen by referring to the upper left-hand diagram, which shows that with the "K" valve there was sufficient air stored in the main reservoir to recharge the brake pipe to 70 lbs. and still leave 83 lbs. in the main reservoir; while with the "H" valves, the air stored in the main reservoir could only raise the brake pipe pressure to 59¼ lbs., at which point the main reservoir and brake pipe pressure became equalized. Therefore, to recharge the train to 70 lbs. with the "K" valves, no work on the part of the compressor was required; while with the "H" valves it required 138 cu. ft. of air and 3 minutes' time, as shown by the lower right-hand diagram. To then raise the main reservoir pressure to that which existed when the application was made required 54¼ cu. ft. and 1.2 minutes' time with the "K" valves; while with the "H" valves it required a total of 217 cu. ft. and 4.7 minutes' time, as shown by the lower left-hand diagram.

This is another case where the comparison is so self-evident that further comment will be superfluous.



NOTE:- AS THESE CALCULATIONS ARE MADE FROM THE STOP DIAGRAMS, NO ALLOWANCE HAS BEEN MADE FOR LEAKAGE; IF ALLOWANCE HAD BEEN MADE FOR LEAKAGE, THE SAVING WOULD HAVE BEEN MUCH GREATER IN FAVOR OF THE K TRIPLE VALVE FOR EXAMPLE; IN THE ACTUAL TEST, IT REQUIRED A PUMP LABOR OF 6 MIN., 7 SEC. TO RECHARGE WHEN TRAIN HAD H-49 TRIPLE VALVES AND 1 MIN., 23 SEC. WHEN TRAIN HAD K TRIPLE VALVES.

FIG. 92. RUNNING TEST. STOPS AND AIR CONSUMPTION.

FIGURES NOS. 93 AND 94.

Figs. 93 and 94 are characteristic charts taken by a pressure recorder during the descent of a grade 200 feet to the mile (4 per cent.) and practically straight. These diagrams were taken from a train of 1,146 tons, equipped with "H" valves. Fig. 93 shows the auxiliary reservoir pressures during the test, and Fig. 94 shows the extreme variations in both the brake pipe reductions required and the cylinder pressures obtained.

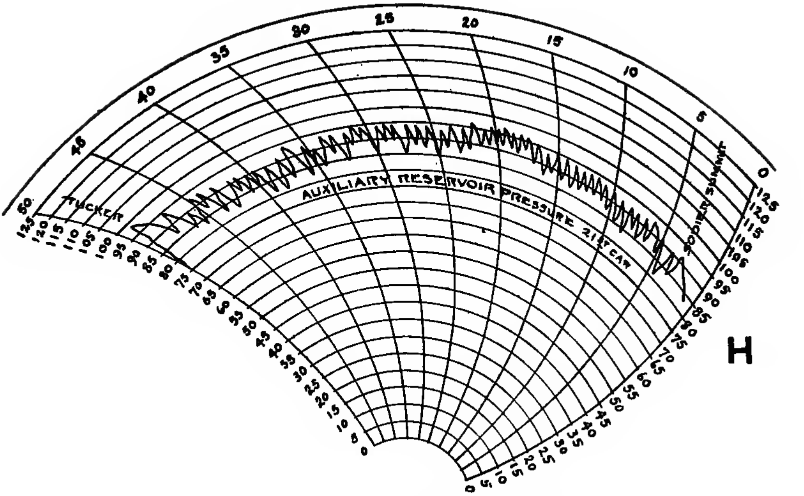


FIG. 93. RUNNING TEST. RECORDER CARD. AUXILIARY RESERVOIR PRESSURE. H TRIPLE VALVES.

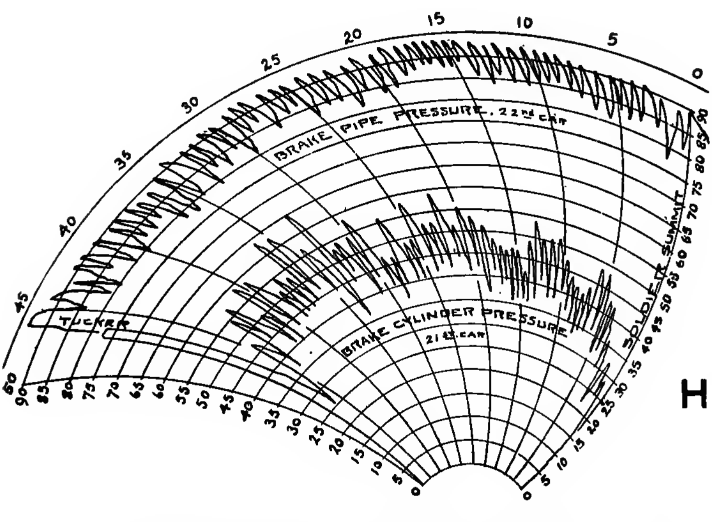


FIG. 94. RUNNING TEST. RECORDER CARD, BRAKE PIPE AND BRAKE CYLINDER PRESSURE. H TRIPLE VALVES.

FIGURES NOS. 95 AND 96.

Figs. 95 and 96 show similar records for tests made with the "K" valves on the same grade and at the same period, the chief difference being that it was found from previous tests that the tonnage could be greatly increased, and in this case it had been raised to 1,505 tons. Fig. 95 shows the auxiliary reservoir chart, which is remarkable for the *uniformity* of its *variation,* if one may be permitted to use this apparently paradoxical expression. Fig. 96 shows brake pipe and brake cylinder pressures which are to be noted particularly on account of the uniformity and the amount of cylinder pressure obtained for the various reductions. The brake cylinder chart in itself is conclusive as to the reasons why the much greater tonnage could be even more safely handled down this grade.

It was demonstrated in this test:—

That the controlling power of the "K" valves was not less than 35 per cent. greater than with the old valve.

That the available time for recharging, comparing the two best runs made with each valve, was as 3 to 1 in favor of the "K" valves.

A much more uniform speed was made with the "K" valves.

It was noticeable to a marked degree that the speed of the train was checked much more quickly with the "K" valve.

The average of the maximum reductions on the different runs was 7.6 lbs. with the "K" valves and 13.3 lbs. with the "H" valves, and it must be borne in mind that the tonnage handled with the "K" valves was nearly twice that handled with the "H" valves.

With the "H" valves the time the brakes were on, compared with the time they were off, was 1 to 1⅓; while with the "K" valve it was as 1 to 3½. This shows how much more time was available in which to accomplish a recharge with the new valve.

With the "K" valves, no matter how light the reduction, there was not a case where the recorder chart did not show a response of the brake on the last car.

Tonnage Demonstration.

While smoother handling, economy of operation, and shorter stops are recognized as the necessary qualifications of an improved brake, the advantage to any particular road is much more apparent if a definite increase in tonnage handled can be shown. From a number of tests which have included demonstrations of this kind, the following are selected as illustrative.

On a prominent Western road having heavy grades, tests were made on two and three per cent. grades to determine the increase in tonnage which could be handled safely with the new equipment over that previously handled with the old. One of these tests was with a train of 39 loaded cars, dynamometer car, and caboose, down a 2 per cent. grade, the present tonnage rating for which being 2,000 tons per train and 55 tons per brake.

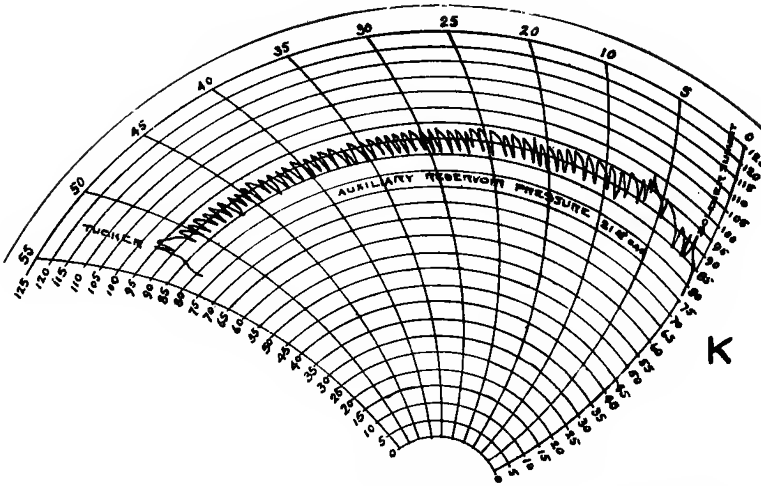


Fig. 95. RUNNING TEST. RECORDER CARD, BRAKE PIPE AND BRAKE CYLINDER PRESSURE. K TRIPLE VALVES.

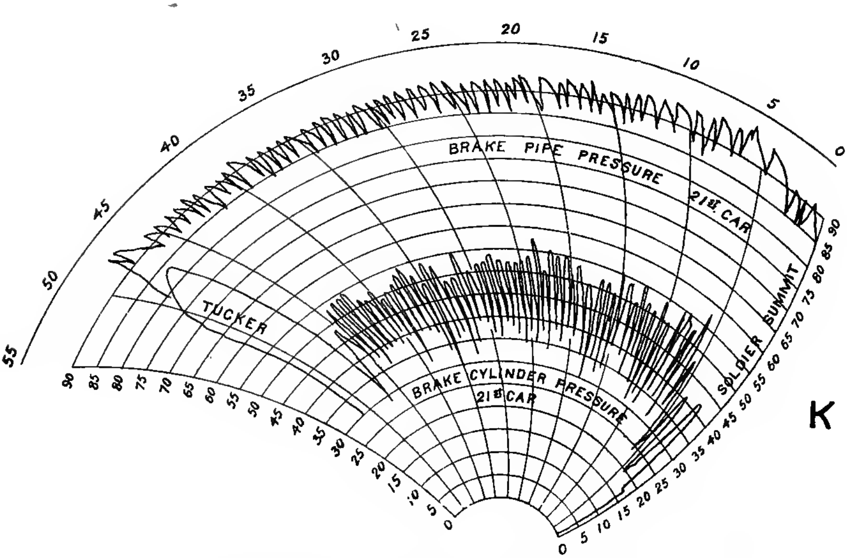


FIG. 96. RUNNING TEST. RECORDER CARD, BRAKE PIPE AND BRAKE CYLINDER PRESSURE. K TRIPLE VALVES.

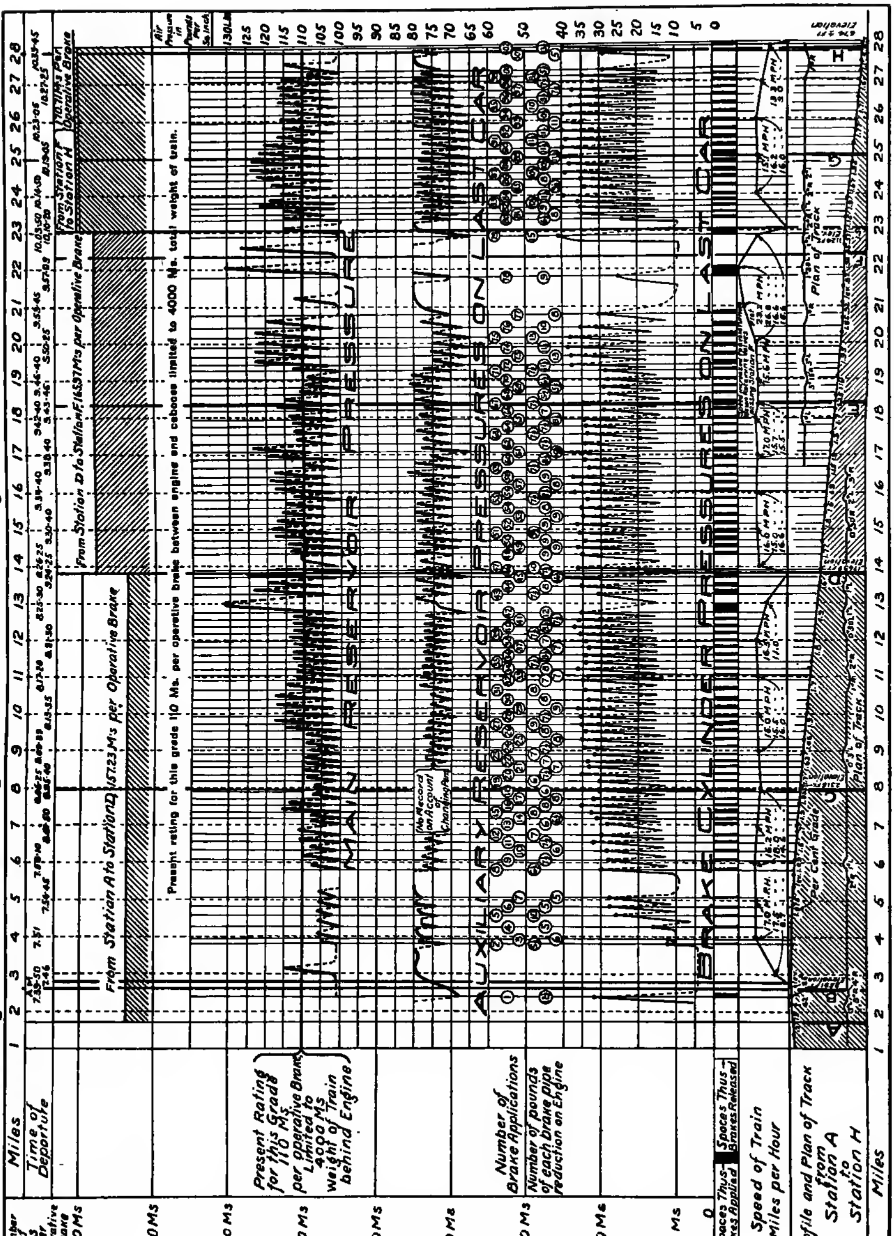


FIG. 97. TWO PER CENT. GRADE DEMONSTRATION. TRAIN OF LOCOMOTIVE, 39 CARS, DYNAMOMETER CARS AND CABOOSE. BRAKE PIPE PRESSURE, 80 LBS. TYPE K TRIPLE VALVES.

A record of this test is graphically portrayed in Fig. 97, which is impressive as illustrating what can be accomplished in the way of safely handling increased tonnage down grades.

Reading from the bottom of the diagram up, there is shown for ready observation, the mile posts, the curvature of track, profile and per cent. of grade each 1,000 feet, speed of train in miles per hour, times brakes were applied and released, brake cylinder pressure on last car, amount in pounds of each brake pipe reduction, serial number of each brake application auxiliary reservoir pressure on last car, main reservoir pressure, present rating of grade, tonnage handled in this demonstration in the different zones and time each mile post was passed.

The chart has been arranged particularly to permit observations, comparatively, of the important points brought out in the demonstration which, in the order of their importance, are as follows: Total tonnage per brake, maintenance of auxiliary reservoir pressure, the light average of brake pipe reductions and the perfect control of train as indicated by the speed diagram.

The new equipment was applied to the cars as they were received at the top of the hill, and at the start of the run the load was 78½ tons per brake. At different points in the descent the train was stopped and brakes cut out until for the last portion of the run the tons per brake were over 85, the total tonnage for the train behind the engine then being over 3,000 tons.

To confirm the statement that the new valves were applied to the train as they were received at the summit of the grade, that is, the brakes allowed to go just as they were, certain cars were found at the foot of the grade after the test with cold wheels, which shows that the brakes on these cars might just as well have been cut out. These, according to the program of the tests as originally outlined, should have been counted out. When this is considered, it raises the tonnage per brake to over 91 tons, or 65 per cent. above that permitted with the old equipment.

During the descent of the grade the main reservoir pressure was never below 100 lbs., the auxiliary reservoir pressure was never below 65 lbs., and the brake cylinder pressure averaged less than 35 lbs., while a possible 62 lbs. was obtainable. The highest reduction made was 16½ lbs., and this in order to stop, and the highest reduction made otherwise was 13 lbs., this being while on a 1.95 per cent. grade. The average reductions made were far below these figures. Thus it will be seen that not more than 50 per cent. of the available braking power was employed, and that a stop could be made at any time, notwithstanding the great tonnage per brake. It should also be noted that the brakes were off for a much longer total period of time than they were on, and that the speed was remarkably uniform, not varying over 2 m. p. h. either side of the average. Another similar test is illustrated in Fig. 98 which is still more impressive in that it shows that for this 3.3 per cent. grade the new equipment enabled the handling of about 80 per cent. more tonnage than the previous standard rating, or an increase of from 40 tons to over 72 tons per brake.

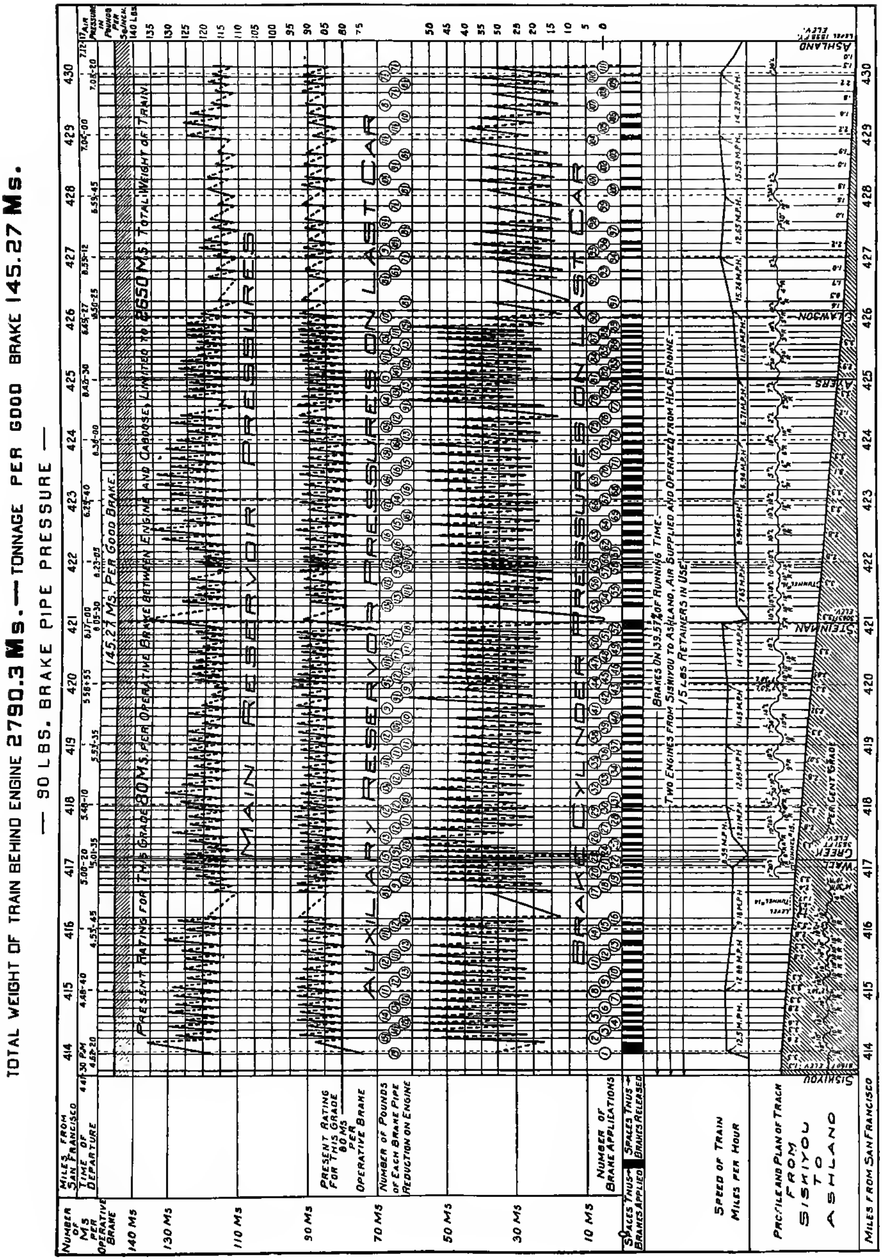


FIG. 98. 3.3 PER CENT. GRADE DEMONSTRATION. TRAIN OF LOCOMOTIVE, 19 CARS, DYNAMOMETER CAR AND CABOOSE. TYPE K TRIPLE VALVES.

From many other tonnage demonstrations, the following are selected as being of interest:

A Western road has some very difficult grades on its main line, and a demonstration was made over this line. The following data pertains to one section of this, the grade averaging over 3 per cent., and being 12 miles long. The maximum tonnage permitted for a good brake was 40 tons, and the total weight of the train between the engine and caboose limited to 2,650 tons. The new valves were applied to the regular trains as they were received—all other conditions being allowed to remain the same—and the control so much improved that the tonnage was gradually increased until it reached 73 tons per brake, or an increase of over 80 per cent., and the observers all agreed without question that the limit had not yet been reached. The speed was maintained remarkably uniform. At no time was more than one-half of the available braking power employed, and was required less than 40 per cent. of the running time. No hand brakes or other auxiliary controlling devices were employed.

Another railroad, with a very heavy grade to negotiate, experienced this difficulty in not being able to get the cars over this section of the road as fast as they were being received, as they were compelled to limit the tonnage and to use hand brakes to assist the air brakes. It was, therefore, decided to equip a train with the new type of valve and see what could be done. A train was made up of 20 loaded 100,000-lbs. capacity cars, the locomotive weighing 240,000 lbs. The weight of the train, exclusive of the engine and caboose, was 1,429 tons, being the heaviest train ever taken down this mountain up to this time. Aside from the application of the new valves to the train, no other changes were made, that is, the pressure carried, the braking power, etc., were not changed, and the engineer was allowed to manipulate the brakes as his judgment and experience dictated.

The average grade was 175 feet to the mile, or 3.4 per cent. and the length 5½ miles.

The tonnage handled with the old brake, assisted by hand brakes, was 1,120 tons.

The tonnage handled with the new brake (no hand brakes used) was 1,429 tons.

Increased tonnage with the new brake was 309 tons.

The percentage of increased tonnage was 27 per cent.

The time consumed with the old method was 40 minutes.

The time consumed with the "K" valves was 25 minutes.

The time saved, 15 minutes, or 60 per cent.

The average speed with the old brake, assisted by the hand brakes, was 8.25 m. p. h.

The average speed with the "K" valves was 13.20 m. p. h.

The increased speed with the new method (all air brakes) was 4.95 m. p. h., or 60 per cent.

The governors had the air pumps shut down 25 per cent. of the time when using the "K" valves.

The average brake pipe reduction required to control the train with the "K" valves was 5 lbs.

A 12-lb. reduction stopped the train equipped with "K" valves from the highest speed, while on straight track and the steepest part of the grade, in 14 rail lengths (about 420 feet), which shows the perfect safety of the train.

Another very similar test was made with a locomotive weighing 347,-300 lbs., and 46 loaded 80,000 capacity cars the train as a whole weighing over 3,000 tons. The grade averaged 58.5 feet to the mile, and the length was 10½ miles. The schedule speed 15 m. p. h.

The train was under perfect control during the whole trip, notwithstanding the speed was permitted to average 26¾ miles per hour. The maximum brake pipe reduction made was 11 lbs., and the average 6 lbs., which, as the brake pipe pressure carried was 80 lbs., was far less than that required to produce the full braking power. The average cycle of brake applications was one minute and forty seconds, and the average number of pump strokes per minute was 82. The temperature of the wheels, when the foot of the grade was reached, was practically uniform, there being none either cold or hot.

Other tests have been made, notably on the D. & R. G. R. R. and the Colorado Midland Railway, where the worst grades of the country exist. In these, the tonnage was doubled, and the safety greatly increased.

These examples are given to show that the new brake is of great value, not only for long train service, but also for grades, not merely as a safety device, but pre-eminently as a dividend-earning investment. This feature of the new brake is the more remarkable since the real cause of its development was to make the brake as efficient for long as it was for short trains—the better control of trains on grades being an increment far beyond what was anticipated.

Summary.

It should be stated here that in comparing the old and new forms of brake devices or in pointing out where improvements have been made, it is with reference to the capability of the old and improved brakes to meet present conditions. It should by no means be inferred that the new brake will more effectively meet the present requirements than the old brake did those of the past—difference in length of train considered—although as a matter of fact, the efficiency of present day *short* train control has been greatly increased as compared with that of the past. With this understanding, keeping in mind the wide range of requirements to be satisfied and the peculiar advantages and limitations of the various forms of apparatus described we may summarize as follows:

1st. Since the pneumatic brake was first established as the brake for railway service, nothing has been developed to supplant it. It has proved sufficiently flexible and adaptable to permit of modification and improvement to meet the ever-changing conditions. Thus, the straight air developed into the automatic, then the plain automatic to the quick action automatic, and to this subsequently were added the high pressure features, and now the improvements which have chiefly occupied our attention this evening, and which, if we are to maintain the comparative efficiency of the brake, are even more necessary than some of those which preceded it.

2nd. The changes in air brake equipment are needed to keep pace with other changing conditions, particularly as these changes invariably operate to reduce the efficiency of the brake, and it is strange that this necessity is seen with other railroad equipment, but not with the air brake. For example: If an increase in engine cylinder diameter and stroke is made, provision is made to generate the steam required; if heavier locomotives and cars are built, the roadbed is improved proportionately; if heavier cars are built, wheels to carry the increased weight are put under them, etc., but the necessity for improving the air brake does not seem to be appreciated in the same way, notwithstanding that it is affected more than anything else, seeing that it must operate on the train as a whole instead of as individual units.

3rd. That with all the brake improvements, it is too much to expect to obtain better control of present-day trains than was possible in the first years of the air brake. It is true that present control can be improved, but this does not mean that it will be greater than before, but that we are returning to our former efficiency.

4th. Ability to apply and release the brakes without fear of shocks, under conditions where they are certain with the old brake, gives an added value to all rolling stock.

5th. As only a comparatively light reduction is required with the "K" valves to apply all the brakes and with uniform cylinder pressure, there is not sufficient braking power in any one part of the train to cause the slack to run in or out severely. On the other hand, with the old brake, a heavy reduction is required to apply the brakes at the rear of a long train, the effect of which is to bunch the slack severely with consequent running out again as the brakes take hold at the rear and the draft springs recoil. As shock is the complement of time and the place where the retarding force is developed, it will be seen that shocks, due to brake applications, will be greatly reduced with the new valve, for while the time required to dissipate the energy of the moving train will be the same, the distribution of the braking power will be different, as it will be divided among all the vehicles in the train instead of first at one end and then at the other.

6th. Because more applications and releases can be made in the same time with the new brake than with the old a much better control and safer operation of the long trains are obtained.

7th. On account of the uniform release feature, and because a maximum or full-service application of the brake is seldom required with the new brake, the release is more prompt and certain at the rear (which, as has been shown, in the vital place of a long train), and the number of "stuck brakes," flat wheels, and shocks are greatly reduced, particularly as no damage can be caused by the engineer opening the throttle before the brakes at the rear have released, as is now the case.

8th. The uniform recharge feature assists in this, inasmuch as the number of "stuck brakes" (resulting from a re-application due to over-

charging after a release) is reduced and a more uniform response of all the brakes is secured if an application is made, immediately following a release.

9th. The quick-service feature makes possible much shorter stops, which is important at all times, but particularly where block signals are in use. This makes quick action applications of the brake unnecessary except in cases of actual danger.

10. The uniform release feature in grade work to a large degree acts as an automatic retaining valve, which is one of the factors in the increased control.

11th. The uniformity of application and release tends to reduce the serious effects of the wide difference of braking power loaded and empty cars in the same train.

12th. That vital factor in train control, the personal equation, is made more uniform, as less skill and judgment is required to get good results, while lack of these cannot result in so much harm.

13th. As the air required to obtain the same control is only one-third of that required by the old brake, there is much less danger of the supply being inadequate, and with brakes in a reasonable operative condition, there is more likelihood of the engineer stalling or stopping than in "losing his air."

14th. Much shifting of lading and breaking-in-two now caused, independent of the brake, by stopping and starting, will be eliminated, as slow downs instead of stops can be made; this, gentlemen, deserves more than passing consideration.

15th. More tonnage can be handled, and at higher and more uniform speeds, than has heretofore been possible, with safety.

16th. Accidents, due to broken wheels, will be fewer, as with the new valve each brake does nearer its share of the work; thus, the excessive heating, due to hand brakes being used, or a few brakes doing the work, no longer takes place.

17th. (1) The old valves are greatly helped by the new ones when mixed in a train.

(2) The new features are simply additions to the old valves.

(3) The old can be converted into the new valves.

18th. From the nature of the case, it is impossible to do more than call your attention to the fact that a great saving (as distinguished from the *earning* capacity of the brake) will result from the avoidance of damage and delays because of the new features and the greater efficiency of the new brake for present day conditions.

19th. We particularly call your attention to the fact that not only has the old brake been one of the vital factors in railroad progress and development, but it is today, the same brake with the new features added, and for the conditions for which it was designed, it has never been equaled. Furthermore, we need only call your attention to the fact that there are over 150,000 of the new valves in service at the present day to show that the new apparatus is well beyond its experimental stage.

20th. And, finally, we think you will all agree that those to whom the railroads of this continent have intrusted, for so long a time and with such success, the control of their trains, have done their part toward maintaining the controlling mechanism up to present day requirements.

The CHAIRMAN—The lively interest of our members in this subject is evidenced by the size of our audience. If there is any one here who has any question to propound, we have here an expert who can fully satisfy him.

Now, in opening our discussion, I will call upon Mr. J. F. Cosgrove, of Scranton, Pa., Dean of the Faculty of the Railway Department, International Correspondence Schools.

Mr. COSGROVE—Mr. President and Gentlemen: When I came down this afternoon I did not expect to be called upon to discuss the paper, because I was unable to even look it over until this afternoon. It certainly is an excellent paper and presents many new ideas along lines that probably few of us have thought of in the past.

One of the first ideas that struck me as important, and it seems to recur frequently in the paper, is the idea that too little importance is attached to the air brake from the standpoint of its efficiency as a money-maker; the general idea being that it is more of a safety device than an expediency in getting trains over the road, thus helping the dividend-earning power. The mechanical department is better acquainted with the value of the brake from that standpoint than is the department which handles the finances, and on that account it is a hard matter, on some roads, to make the management realize the importance of adopting the later form of brakes. To their best knowledge, the brakes in use seem to be stopping their trains satisfactorily, so why should they go to the expense of the new equipment? In the press of their duties they have not given the subject sufficient thought to realize that anything that affects greater safety to the traveling public, gives greater protection to the rolling stock and freight, permits of increased speeds, longer and heavier trains, and greater frequency of train service, thereby makes both the equipment, the men and the track available for increased service and very materially increases the earning power of the road. The idea has never been presented to them in this light. Had it been, the air brakes and the entire air brake department would receive much more consideration at their hands.

On the other hand, anything that helps the motive power helps the acceleration of train movement and is given careful consideration by the management. The power is equipped with the latest devices. Why? Because the new devices are advocated on the basis of the saving they will effect is adopted. They are not represented as a precaution, but are exploited as a dividend-earning device, having a definite earning capacity, and as such the management can readily understand their necessity.

If the mechanical department desires to adopt an approved air brake appliance, or air brake system, or to have better maintenance of the brakes, they should advocate it on exactly the same basis as they would the adoption of an improved mechanical device for the locomotive. This method

will soon bring the management to the point where they will give the brake its true value relative to the movement of trains, and will result in very materially raising the standing of the air brake and of the air brake department.

The improvements that have been effected in the air brake from time to time since its adoption, permit of freight trains being increased from 15 cars in the old days to over 100 cars today, with a tonnage fifteen times as great as formerly. Also higher and more uniform train speed and greater train frequency are now possible with safety. This had enormously increased the tonnage haul and at the same time greatly decreased the cost per ton mile for haulage. Increasing the tonnage, speed and train frequency, increases the capacity and thus the earning power of the road, the motive power and cars, and the men; at the same time the factors of safety and the degree of control of long trains have been greatly increased.

In passenger service newer forms of brake permit the speed to be increased from 40 and 45 miles per hour to 60 and 70 miles per hour, and makes possible the 18-hour train between New York and Chicago. Notwithstanding that coaches have increased in weight from 20,000 to 150,000 pounds the speed is made possible, practicable, and safe by the new apparatus. Not only are these high speeds made possible, but trains several times the weight are hauled at these speeds with safety.

Longer and heavier trains hauled at high speeds with greater safety, better control, and with a considerable saving in time during stops and slow-downs are advantages that will appeal directly to management of railroads, if they are made fully conversant with them. I think this paper is timely, and I believe that it will have the effect of enlightening a great many on the *earning capacity* feature of the brake; it certainly will place us in a position whereby we can go forth and spread the doctrine. (Applause.)

The CHAIRMAN—I will ask Mr. T. L. Burton, General Inspector of the Central Railroad of New Jersey and the Philadelphia & Reading Railway, to make a few remarks on this subject.

MR. BURTON—Mr. Chairman and Gentlemen: In attempting to discuss at this time the paper of the evening we are confronted with several obstacles. First, those who know the author, as many of us do, appreciate the fact that there is usually but little to be criticized in and nothing to be added to his writings. Second, the paper is of such magnitude as to make a detail discussion on the various subjects with which it treats an impossibility in the short time that is available for discussion; moreover, I have not seen a copy of the publication in its present form. The Secretary of the Club very kindly sent me a galley-proof of the paper a few days ago, but it was received as I was leaving town to be away until to-night. My absence has, therefore, precluded the possibility of preparing from information at hand, data pertaining to the subject which is now before you for consideration.

In reading over the paper hurriedly, however, it seems to be divided into five separate and distinct parts, namely: The changes in train operation which have made the development of the air brake to its present stage, necessary, advisable, or possible; the development of the locomotive brake, the development of the passenger car brake, proper braking power for passenger cars and the basis from which the same should be calculated, and the development of the freight brake.

Of the parts of the paper which have been mentioned, the ones pertaining to passenger service are the ones to which I have devoted the most thought. What I have to say shall, therefore, be confined to the type of equipment and the amount of braking power best suited for this service. As the paper very ably states, in determining the proper braking power for cars, two objective points must of necessity be kept constantly in mind—the maximum that can be used in service braking without destroying the flexibility of the brake in making station stops, etc., and the maximum that can be employed in emergency without causing disastrous wheel sliding. With due regard for both, the paper resolves itself into recommending 90 per cent. of the light weight of the car, based on 50 pounds cylinder pressure, which is equivalent to 1.8 per cent. for each pound of pressure that may be in the cylinder at any one time.

The old method, which is still extensively employed, is to brake passenger cars at 90 per cent. on 60, which is equivalent to 1½ per cent. per pound of pressure. You will thus see that the proposed change in the base of the calculation is equivalent to increasing the braking power 20 per cent. —using the old method as the unit base and assuming that the pressure is constant in both cases.

It is very gratifying to have a man of Mr. Turner's ability and reputation come before an audience of this kind and make such a recommendation. It is more gratifying, to me at least, to realize that some of the leading and largest roads in the country have adopted the recommendation in question.

This gratification on my part is due in part to the fact that as far back as 1901 the passenger car equipment of the Central Railroad of New Jersey was braked in accordance with the proposed method (1.8 per cent. per pound of cylinder pressure), and the results obtained from such practice were remarkably good.

It is true that the brake pipe pressure employed, at that time referred to, was rarely above 70 to 90 pounds, so that the maximum braking power obtained was seldom more than 90 per cent. Our practice, therefore, demonstrates nothing with regard to wheel sliding in emergency braking, but it did afford an opportunity to observe the practicability of using 1.8 per cent. braking power per pound of cylinder pressure without destroying the flexibility of the brake for service stops.

In 1903, preparatory to the adoption of the high speed brake, we made an exhaustive series of brake tests in which was demonstrated the practicability and desirability of using the percentage of braking power, of

which I have spoken, in connection with 110 pounds brake pipe pressure and the high speed brake, which at that time was standard and the best obtainable.

In applying the high speed brake, after the conclusion of the test which led to its adoption, the practice with regard to braking power was changed from 90 per cent. on 50 to 90 per cent. on 55, or from 1.8 to 1.64 per cent. per pound of cylinder pressure. This change was not made because of dissatisfaction with the former practice, but because we were handling in interchange a number of cars from connecting lines which were braked at 90 on 60. We did not feel disposed to do all of the braking in through line and interchange service.

From seven to eight years' experience with approximately 600 cars braking at practically 1.8 per cent. per pound of cylinder pressure and operating in almost every imaginable class of passenger service, I would consider it entirely proper to use such braking power for passenger equipment cars.

The author further recommends, for use in conjunction with the leverage ratio referred to, an air hrake equipment with which 104 pounds cylinder pressure is obtainable for emergency braking and with which this pressure will be retained in the cylinders throughout the length of the stop. I can best comment on such a recommendation by referring to some brake tests which were recently made on the Philadelphia & Reading Railway with modern passenger cars, on which were developed 178.6 per cent. brake power throughout the stop, with no excessive wheel-sliding.

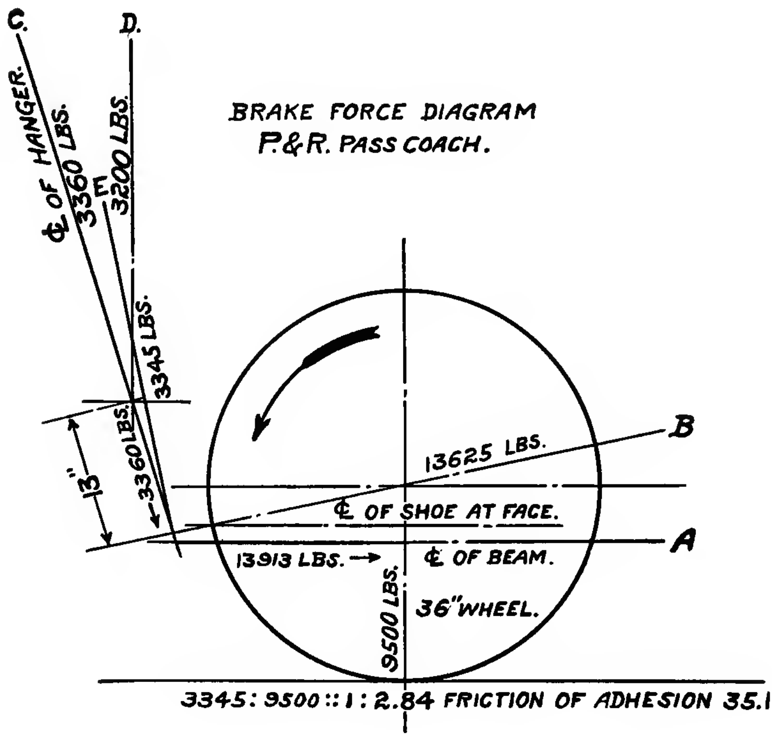
The question frequently arises as to how we can apply such braking power and retain it until the stop is completed without disastrous wheel-sliding. Mr. Turner explains this point clearly in so far as concerns loss in coefficient of brake shoe friction, as results if high shoe pressure, high speed and continuous rubbing incident to stopping from high speed, but a careful analysis of the subject discloses a number of other losses to which no reference is made in the paper, and which frequently reduces the actual or effective braking power to a point much below the nominal or calculated power.

To illustrate the point in mind, I will exhibit a diagram showing such analysis of the Reading test and endeavor to explain where some of the losses occurred.

The cars with which the tests were made weighed 76,000 pounds and were equipped with four-wheel trucks, the average weight at each wheel being 9,500 pounds. The calculated braking power, as previously stated, was 178.6 per cent. of the weight of the car, making the nominal brake load no each brake beam approximately 34,000 pounds, or to be exact, it has 16,994 pounds per shoe.

We know there is a certain loss in transmitting the brake force from the brake piston to the shoes, and while the exact loss from this source is not always known, it is believed to have been, in the case under consideration, about 18 per cent. of the nominal, which if true would make the actual pressure at the end of the beams 13,913 pounds, which is equivalent to 146.4 per cent. of the weight on the rail.

The braking load on the beam is transmitted from the truck levers through a line (A) parallel to the track and at a point above the rail corresponding to the center of the beam.



The load from the brake beam is transmitted to the wheel through a line (B) drawn from the center of the shoe to the center of the axle and is equal to 13,625 pounds, or 143.4 per cent. of the weight on rail.

The upper end of the hanger links were attached to springs at the intersection of C and D, which were secured to the truck. The springs were carefully calibrated in a testing machine before applying them to the truck, so that the load carried by the springs at any height from solid compression to maximum free height was known.

By measuring the height of the springs at the approach of the stop the maximum pull on the brake beam hangers could be determined.

During the last few feet of the stop the springs registered a pull vertical to the track through line (D) of 3,200 pounds. The hangers, however, were not parallel to the springs, so that the loads on the two were not uniform. Taking into account the angle of the hanger to the spring centers, in order to develop a pull of 3,200 pounds on the spring, we must first have a pull of 3,360 pounds on the hanger (through line C). The

angle of the hangers to the wheel tangent at the center of shoes was such as to give us a tangential pull on the wheel through line E of 3,345 pounds, then the ratio of this pull to the force 13,625 pounds through B gives us an equivalent coefficient of brake shoe friction of 24.5 per cent.

As the wheels would invariably slide when a vertical spring pull of 3,200 pounds was registered, the ratio of the tangential pull of 3,345 pounds to the weight 9,500 pounds on the rail should, by disregarding the rotative energy of the wheel and the transfer of a portion of the weight from the rear wheels in the truck to the forward wheels during an application of the brake, give us a coefficient of friction between the wheel and rail of 35.1.

The illustration would seem to confirm the author's statement that the coefficient of friction between a steel-tired wheel and the rail is frequently in excess of .25.

While the coefficient of brake shoe friction is shown to be decidedly in excess of what the author says should be expected, there may be a means of accounting for the difference, *i. e.*, he is considering a much higher speed and shoe pressure than was developed in the test under consideration. Our maximum speed was fifty to fifty-five miles per hour and the cars were much lighter than Mr. Turner has in mind. It is also true that the coefficient of brake-shoe friction to which I have referred was not developed until the stop was practically completed. Unfortunately, the springs which were used in making the test were not sufficiently flexible to register the hanger pull at all stages of the stop.

Type "P" (old style) brake equipment was used in making the test, and the maximum cylinder pressure obtainable with this equipment being 90 to 94 pounds, in order to obtain a total braking power of 178.6 per cent. of the weight of the car it was necessary to use a leverage ratio suitable for 1.9 per cent. per pound of cylinder pressure. It was observed that such leverage ratio was too high for satisfactory flexibility in service braking, though the maximum brake power of practically 179 per cent. was believed by those who attended the test, to be practical for emergency stops.

Our experience in this connection emphasizes, in my mind, the advantages to be derived from using an air brake equipment with which a much higher cylinder pressure can be developed in emergency stops than would be practical for service braking. I, therefore, wish to indorse that part of the paper in which reference is made to the gap which should exist in the desired cylinder pressure for emergency stops and the maximum permissible, in a given time, for service braking.

In Figure 33, page 76, of the paper will be found retardation curves representing two stops made with a train of ten cars and two locomotives, equipped in one case with the new brake and in the other with the so-called old brake. The difference in the length of stops illustrated is in favor of the new equipment, but both stops are decidedly discreditable especially in view of the high brake power that was used in conjunction with the new brake, by means of the high cylinder pressure that was used with this equipment without a reducing mechanism.

It will be observed that the speed in both cases was approximately 84 miles per hour, and the length of the stops was 2,591 and 3,062 feet respectively with the new and old brake.

In 1903, there was made on the Central Railroad of New Jersey a series of brake tests in which trains of three cars and one locomotive were stopped from speeds of 80 miles per hour in 2,100 feet. The same train should be stopped from the speed shown in Figure 23—84 miles per hour—in about 2,300 feet.

The Central train was braked at 1.5 per cent, per pound of cylinder pressure, the maximum cylinder pressure being 82 to 84 pounds, the maximum braking power was about 125 per cent. and owing to the high speed reducing valves reducing the cylinder pressure to 60 pounds before the stop was completed, the mean effective brake power was much below the maximum. Moreover, the Central train was shorter than the test train referred to in the paper, which gave the latter an advantage over the former, as a much greater distance is required for stopping a three-car train from a given speed than is required for stopping a longer train.

The test shows, however, that the Central train equipped with the old brake, could be stopped in over 10 per cent. shorter distance than the train referred to in paper as being equipped with the new brake, developing a decidedly higher brake power.

I do not draw this comparison with a view of discrediting the brake equipment which was used in making the stops referred to in the paper. To the contrary, the point is raised to illustrate the fact that in trying to bring our passenger brake equipment up to a standard that will insure making the shortest possible stops in time of danger, all of our energies should not be devoted to the air-operating parts. There are a number of other things of equal importance that should receive due consideration in our efforts to perfect the service.

It is an unquestionable fact that the decidedly effective stops which were made in the Jersey Central test, were due in part to the condition of the cars, trucks, brake shoes and foundation brake gear. The latter was very light proportionately to the work required, which insured a minimum loss in brake power in transmitting it from the brake cylinder to the wheels.

The time is undoubtedly at hand when those who have to do with the design and installation of brake gear should carefully consider the use of such forgings as will insure maximum strength and minimum weight.

Specifications of the Master Car Builders' Association for high speed brake details provide for a maximum fiber stress in levers of 23,000 pounds. These specifications provide for wrought iron forgings and they provide ample strength for such forgings. A number of roads are now making brake levers for passenger cars of steel. Owing to the difference in the maximum bending movement of steel and wrought iron, the steel lever should be preferable from the point of reducing weight and resulting loss in brake power.

There is more that I should like to say on the paper, but lack of time prohibits further discussion on my part. I thank you for your attention. (Applause.)

The CHAIRMAN—There are a number of gentlemen here who are amply able to discuss this subject and probably wish to speak on it, and in throwing the subject open for general discussion I only wish to add that they bear this in mind and at the proper time look out for your braking facilities. (Laughter.)

The subject is open for general discussion.

Mr. Albers, do you wish to add a few remarks to what has been said?

MR. L. H. ALBERS (New York Central & Hudson River Railroad)—Mr. President and Fellow Members: In my opinion, the paper just read is one of the best that has come to my notice, and I believe my library contains nearly everything pertaining to the subject of Air Brakes. The paper is a lengthy one, therefore I am glad Mr. Turner was considerate and omitted some of the points contained therein, as it affords me an opportunity to touch on one or two of them.

Fortunately, I received my copy at an early date which gave me ample time for perusal, and it was to me the pleasure received by a little boy with a good story book who cannot leave it and go to bed. Many here present have been in the same boat. I am sure you have read many a night until your mother insisted upon your going to bed. In this particular case I was going to do likewise, but being a *benedict*, I was politely invited to come to bed. (Laughter.)

One of the points which impressed me more than any other is shown in photograph on page 77, which, as I take it, shows an engine broken away from train and an emergency application made. I happened to witness a number of these tests which were vividly brought back to my mind in the photograph.

Studying the table, or figure 33 on page 76, we find the results of tests the cars and engine having new brakes, a gap of 427 feet between the engine and cars existed after the stop was made. Further, it is noted that with the engine and cars having the old brake, a gap of 1,515 feet existed after the stop was made. It seems hardly possible that there should be a gap of 1,515 feet, which of course you will note has been greatly reduced by the new brake. The point I wish to illustrate is that with the old engine brake (driver brake) the calculations are based on 75 per cent. braking power on 50 pounds cylinder pressure, while with the new brake the calculations for the driver brake are based 60 per cent. on 50 pounds cylinder pressure, which, under an emergency application in the former, we obtain about 112 per cent., while in the latter 114 per cent. is obtained. This is due to a somewhat higher brake cylinder pressure under an emergency application with the new brake. Yet, when considering that the percentage of braking power under an emergency application with both brakes is practically the same, it proves the value of the retaining feature of the new brake and that, practically, we have been running our engines with no brake for years.

I believe it would be possible to arrange the engine brake so the stops can be made at even less distance than shown with the new engine brake. As I understand the new car brake under an emergency application gives between 104 and 105 lbs. brake cylinder pressure, and this pressure is held until the train has made the stop, which gives about 187 per cent. braking power, while with the new engine brake, under an emergency application, about 95 lbs. cylinder pressure is obtained, which pressure is blown down to about 68 lbs. with a safety valve, naturally reducing the percentage of braking power below 114 per cent., while on the cars, as stated, it is held at about 105 lbs., or 187 per cent. until stop is made.

It seems evident that the Superintendent of Motive Power has a complaint to make in view of the fact that the car brakes have been given the advantage of bottling up the air during the emergency application, while part of that on the engine is being wasted.

I believe further consideration is due the engine brake, and if the bottling can be done on the cars, it might be carried still further and enable us to have the stop made in far less than 427 feet, as given with the new engine brake. (Applause.)

The CHAIRMAN—We have heard from two steam railroad men, and we would like to hear from the electrical men. I will ask Mr. Munger, General Manager of the Hudson Companies, to add a few words to the discussion.

MR. MUNGER—Mr. Chairman and Gentlemen: I regret that I did not receive the paper in time to carefully read it. I received it only yesterday. In glancing over the paper I find it to be full of meat, and as the gentleman who preceded me has said, it is by far the best air brake paper that I have ever seen.

Four years ago I was with the road which was the first to be equipped with the graduated release brake, and I think great credit is due to the author of the paper of the evening, Mr. Turner, that that application was made and that it proved entirely satisfactory. The brake is absolutely fool-proof, as has been shown by about four years of service There were some rear-end collisions on the road, but no trainmen ever laid them to the brakes. The brakes were never known to fail in service, and consequently the trainmen never thought of their failure as a possible explanation of trouble.

The car mileage of the road mentioned above was about one million passenger car miles per month. As to the cost of maintenance of the graduated release brake I would say that it is no more than the plain automatic brake. In regard to flat wheels, I would say that we never had any flat wheels because of the brake. (Applause.)

The CHAIRMAN—I will call on another electrical man, Mr. J. S. Doyle.

MR. DOYLE—Mr. Chairman and Gentlemen: I want to say that I did not expect this invitation and am, therefore, unprepared to say much tonight. I might say, however, that Mr. Turner appeared in New York some four or five years ago to advocate the long-looked-for graduated release and quick recharge automatic type of brake. We listened to him as patiently as to his predecessors, and his design looked so promising that we finally allowed him to equip a train in regular service, which, if I recall it correctly, was the first time this apparatus was given a service trial. This train was continued in service for a year and a half, and performed so satisfactorily that we finally decided to discard the regular type of automatic brake employed on our Subway Division and install the new apparatus. The requirements of our Subway Service are, as you all know, very exacting, and this type of apparatus has performed the service better than the old type of brake. (Applause.)

The CHAIRMAN—The Pennsylvania Railroad has probably gone more largely into the steel passenger car equipment than any other road in the country. Mr. J. R. Alexander, General Road Foreman of Engines of the Pennsylvania Railroad, is here this evening, and I will ask him to address us on this subject.

MR. ALEXANDER—Mr. Chairman and Members: It has been my privilege during the past few years to have something to do in the handling of trains in service, so that I am somewhat familiar with what I might term the old and the new standard brake, as outlined in Mr. Turner's paper; the old standard having reference to the quick-acting automatic brake equipment for locomotives and cars and the new, which consists of the "ET" engine and independent locomotive brakes and quick service and retarded release types of triple valves for car equipment. I would like to say, as an operating man, that I will accept Mr. Turner's very able paper as a round-up and complete analysis of the various improvements that have been brought out from time to time in the matter of air brakes for railway train service.

Referring to the new equipment which many have had some experience with in different parts of the country, the line with which I am connected have in service quite a number of the new engine equipment and some of the car equipment, and I can assure you that everything that has been submitted by the author of the paper of the evening as being a possible or actual improvement is thoroughly borne out by our experience with this equipment. We do not have any trouble in having the new brakes properly handled that cannot be corrected by proper instructions and supervision. I have heard a great deal of criticism, pro and con, in regard to the results that can be obtained from the fact that these new wrinkles that are brought out are not readily adopted by the men and they cannot keep up with the improvements without receiving a certain amount of practical instructions and demonstrations, or in other words, the air brake instructor must constantly be doing good missionary work. Those of us who have to do with the education of engine and trainmen on railroads, will agree with me when I say that we have had less trouble

in teaching men to handle the more recently improved automatic brake appliances than was experienced in teaching them to handle the old plain quick-acting automatic brake in the early development of train brakes, and the reason is plain, because all of the improved devices that have received the approval of the various railroads have been made in the direction of simplifying in some way the manipulation or the operation of train brakes.

Another thought I hear advanced to-night is that it is difficult to have the management of our different railroads take up these apparently new inventions; in other words, to spend the money to get the best there is to be had. This I rather doubt, and think that the real trouble lies in the fact that there is a middle class which is somewhat slow to adapt themselves to the new conditions, or possibly to have the courage to stand steadfast to their convictions. I refer particularly to the air brake experts employed by the different railroads who have not kept in advance of the times and have not laid before their management with sufficient emphasis the full value of this new development. For that reason alone, our superior officers would hesitate to go into the large expense involved to equip their locomotives and cars with something different from the present standard equipment until time, or the other fellow, has developed the fact that there is no argument needed to show the advantage of the new apparatus over the old. From my experience and observations there should be no hesitancy whatever on the part of the air brake inspectors in taking up and making all needed recommendations for what is called the new air brake equipment, as far as its practical application will suit the local conditions existing in their respective territory.

Concerning the type "L" triple valve as used on passenger equipment cars, we find, from observation of quite a number in service, that their performance is entirely satisfactory, and in fact so much so that they are now being applied to all-steel passenger equipment cars, and quite a large number of the new locomotives have been equipped with the new "ET" equipment. I can assure you that the best recommendation for the equipment mentioned, *i. e.*, the "ET" engine and tender brake and the type "L" triple valve, is the results obtained in service.

The CHAIRMAN—Does any gentleman volunteer any remarks?

(A member arose in the audience to speak.)

The CHAIRMAN—What name, please?

The MEMBER—Mr. R. H. Blackall. I came down here to-night because I am interested in the subject presented, but, from my standpoint, it is to be regretted that the Chairman has asked us to curtail our remarks, as I have been a member of this club for about twelve years and have paid about $24.00 into the treasury; this is my second visit to the club in that time. I was not prepared to speak, as I had not read the paper, but thought this would be a fine opportunity to let the blessed sound flow on and get my twenty-four dollars' worth. (Laughter.)

The paper presented to-night shows a great deal of thought and it sums up a great many years of experience and the expenditure of an immense sum of money in getting to the point of the art at which we have arrived.

As I listened I could not help but think that we are still the same, in a way, as we were when children. The three meals a day came to us then, and a comfortable place to sleep, but we never had a thought of the many sacrifices and the immense amount of striving necessary to make such comfort possible; we are likely to take things as they come without counting the cost.

There are very few here who have any conception of the immense amount of work, energy, expense, disappointments, etc., that are a necessary accompaniment to the development of such an art. The brake of five years ago has been revolutionized, and there is no question but that Mr. Turner is entitled to a considerable share of credit for the changes that have been made, and he has certainly had the most loyal support from the Westinghouse Air Brake Company, which has spent thousands of dollars in perfecting the devices referred to in the paper to-night.

Not being connected with the Westinghouse Company, I feel that I can say a word about what has been done. Take the "K" triple valve: there were two years when the work on this valve was practically a night and day proposition, and not less than twelve or fifteen sets of quick-service triple valves were designed, built and tested. After passing the rack test they were taken out and tested under actual road conditions. For this test two miles of track, an engine and train crew, a test crew and from 50 to 65 cars were reserved for about six months with which to try out the valves. Instructions were given that the new valve must not be helped by the use of latest modern equipment, so the valves were tested out with wooden cars that had seen eleven and twelve years of service and were equipped with single spring draft gear.

The first valves tested were so severe in their action that they were out of the question, and it was not until several new valves had been made that they would finally give all of the results with which you are familiar, but this was done without producing any more strains in the train, and in most cases much less, than would the older form of triple. Part of the train was also loaded, to be sure that the slack action would be satisfactory in all respects and under all conditions.

The valve was developed with this old weak train to such a point that, finally, the slow-acting valves could be placed on the front half of the train and the quick-acting ones on the rear half, and no objectionable results were obtained.

In the discussion to-night the freight equipment seems to have been entirely neglected, and this, to me, is the more important of all. It was my good fortune to be connected with the development of this valve, and to be the first to try it out on the worst grades of the mountainous West. Among these were the Soldier Summit grade of the D. & R. G., the Cardiff

Branch grade of the Colorado Midland, and practically all of the heavy grades of the Northern Pacific; we also tried it on the 200 foot grade on the South Fork Branch of the P. R. R.

My experience on the grades was such that I am safe in stating that there is not a set of operating conditions that can be presented to-day that the Westinghouse Company cannot meet with their new equipment if the engine is given the proper pump and main reservoir capacity and the car equipment is given the proper maintenance. (Applause.)

The CHAIRMAN—Mr. Blackall has had his twenty-four dollars' worth. Mr. Frank Hedley, Vice-President and General Manager of the Interborough Rapid Transit Company.

MR. HEDLEY—Mr. Chairman and Gentlemen: Like the rest of the speakers, I did not have an opportunity of looking the paper over and, did not read any part of it until this evening. Some points have struck me with a great deal of interest, having known something about the brake that Mr. Turner has written about here. It was first called to my attention about five years ago. Mr. Herman Westinghouse came to my office and told me what he had in a general way, and after I had talked with him for a while I thought it had some merits, and he said, "I will bring around in a day or two Mr. Turner, who can talk with you in detail about this brake and what it will do." In two or three days Mr. Westinghouse brought around Mr. Turner. I looked him over carefully, and it did not take me very long to decide Mr. Turner was full—(laughter)—of his subject. Now, sometimes, as you know, I have to explain the reasons why we do not do things. We are in the stopping business, and we have a great many things to stop, and incidently we have to stop heavy trains very frequently. I do not know of any place where a heavy train service exists where the value of a second or the fractional part of a second for each one of their stops means so much revenue to the railroad company. It is mentioned here in the paper on page 13, that sometimes the railroad officials give more attention to the matter of the color of the paint on their cars than they do to the air brakes. I assume that that is good news to the paint men (laughter), but I do not agree with Mr. Turner in that respect. In fact, I know it is not so in so far as the Interborough Company is concerned. One of the speakers stated that a few years ago on the line with which he was connected they put on this new kind of brake, and that after they put that brake on they had some accident. I assume that he refers to tail-end collision, or an accident where the motorman did not stop his train as soon as he should have done, and perhaps went into the tail end of another train. I was more than glad to learn that it was not due to any fault of the new air brake. But, now that we have this new kind of brake in use, I suppose they will still come to the management with the same old story. (Laughter and applause.)

The CHAIRMAN—Now, this meeting will not be quite complete unless we hear from Mr. H. H. Westinghouse. I will ask him to give us a few words.

MR. WESTINGHOUSE—Mr. Chairman and Gentlemen: This opportunity to address you is an unexpected pleasure, although I feel little can profitably be added to what has been said upon the subject treated by Mr. Turner, as he has clearly explained the present status of the braking problem and the changed conditions calling for improved brake devices of a character described by him.

I will, however, take advantage of this occasion to refer to the importance of adequate maintenance of brakes and a requisite degree of skill on the part of operatives to secure proper operation, if reasonable efficiency from their use is to be realized. As manufacturers of brake apparatus, we sometimes feel that there is a lack of realization on the part of those using brakes of how little value the best brake apparatus is, if not kept in order and intelligently manipulated. No more useless expenditure can be made than for brakes that are not properly maintained, for they, then, not only fail to perform as expected and desired, but not infrequently become a hindrance rather than a help to the movement of traffic when these wrong conditions are allowed to develop and continue. So-called brake failures, including runaway trains and stuck brakes, are the direct result either of poor maintenance or improper manipulation on the part of the operatives.

I believe one reason for lax brake maintenance will be found in a tendency among many railway officials to class brakes with other parts of railway mechanisms—such as wheels, springs, couplers and similar devices having no operative functions that are not performed automatically, their use being entirely independent of manual operation, and calling for but little in the way of inspection and repair, the effects of use and wear being corrected by replacement.

With brake apparatus, however, conditions are wholly different, for no other single element of railway mechanism, possibly excepting the locomotive, requires more frequent manipulation or demands such rigid and frequent inspection. Its successful operation requires that every trainman, as well as a considerable force of shop and round-house men, shall have special training, as evidenced by the large number of air brake instruction plants and air brake courses given by correspondence schools.

Still, with all that has been done and is being done, a great opportunity for improvement yet remains, which will be approximated when those in authority realize that the question of training and proper provision for brake maintenance and inspection is a continuing one. It has been our experience that when the attention of railway officials is called to this subject, a hearty and usually efficacious effort in the right direction is made, and frequently with excellent results. But I regret to say that in too many instances, due possibly to the necessity for reduced expenditures or a belief that the job is finished, there has been a discontinuance of the course that brought about improved conditions, with the natural consequence of a return to the previous state of inferior braking. I believe it is becoming more evident to all those interested in the subject that a high brake efficiency is of great commercial value, but if it is to be secured and preserved, it is essential that adequate air brake departments should be established and maintained, competent to both care for the apparatus and educate men to its proper use.

The CHAIRMAN—We might carry on this discussion for another hour with pleasure and profit, but it is growing late, and I will ask Mr. Turner if he wishes to say a word in conclusion.

MR. TURNER—I just wish to say that I hope there is no one here who will omit to read the section of the paper which treats of "Braking Power and Wheel Sliding." In that you will find we state the reason why we can use as much as five or six hundred per cent. braking power without sliding the wheels and also explain why this great braking power does not result in sliding wheels as we approach the end of the stop. That is a most important chapter as far as the technical or safety side of the brake is concerned in the paper, and I am sorry I did not have time to read that particular chapter.

In regard to the point made by Mr. Burton as to the length of the stops, I may only say that these tests were made on the same train, the triple valves only being changed, using the braking power employed by the road generally. We did not increase it, as we would have done had we desired or concluded to make as short a stop as possible. The tests were simply to show the comparative stops under the service conditions as they were found and were not by any means intended to show in how short a distance the train could be stopped. As to the relative efficiency of the two equipments, however, the results are strictly comparative.

Mr. Albers raised a question about locomotives. I may say it is an unsolved problem, just what to do with the locomotives. It is doubtless true that the heaviest vehicle in the train should be the most effectively braked, yet you will see in the paper that the locomotive will run almost twice as far as a car when cut loose.

As regards the statement that the management gives more attention to the painting of the cars than to the air brakes, I would say that Mr. Hedley is different from some railroad managers in this respect, for I know that he has given a vast amount of study to the subject of train braking, and he certainly has the safest and best equipment anywhere in this vicinity on his lines; therefore I wish to remove any wrong impression Mr. Hedley may have regarding *all* managers being more careful of the paint on the cars than they are of the brakes. (Laughter and applause.)

The CHAIRMAN—On behalf of the Club and its officers I wish to thank Messrs. Turner and Dudley for the papers they have presented this evening, as well as those of our members who by their discussion have contributed to the development of this very interesting topic. The next in order is the election of the members proposed at the meeting of March 19th. The number is sixty. It has been regularly moved and seconded that the secretary cast one ballot for their election. The secretary informs me that that has been done, and they are declared duly elected.

WHAT STOPS A MOVING TRAIN?

By S. W. Dudley.

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You are, doubtless, most of you, familiar with that picture of the first railroad train, drawn by Stephenson's wonderful locomotive, with its barrels of wood fuel on the tender and the stage-coach-like wagons in which the complacent passengers were without doubt congratulating themselves on the enjoyment of the most rapid form of locomotion possible to man. This locomotive was furnished with a steam driver brake, in principle much like the cam brake still used. The coaches had no brakes at all, or hand brakes of the simplest form. And these means were probably ample to meet the requirements of what was then considered a dangerous service.

As the growth from these small beginnings continued, hand brakes on each car were found necessary, and for a long time such brakes, whic. could be applied with sufficient power to slide the wheels, if desired, were accepted as a sufficient and satisfactory means of controlling trains. For after the brakes had been set hard enough to cause the wheels to slide, what more, indeed, could be asked?

The next step was to put the means for operating the brakes on all the cars in the train into the hands of one man, namely, the engineer, which not only placed the complete control of the train where it naturally belonged, but made possible a much more prompt and effective operation. Devices, such as chains or ropes, extending through the train, were tried, but these were soon displaced as the advantages of compressed air became known. In compressed air the engineer was, in effect, furnished with a powerful spring, which he could apply at will, through the necessary brake gear to the brake shoes throughout the train, and allow the force which it possessed by virtue of its compression to act upon the wheels in such a way as to stop their rotation.

We need not dwell upon the early forms of straight air brakes by which this method of control was accomplished. As you all know, the system had two important defects, which, as trains grew longer and heavier, and speeds higher, became prohibitive. These were the necessary slowness of its operation and the complete loss of braking power which would result from a rupture of the pipe connections. These two important safety features being absent, the further progress of train operation was accompanied by such risks as were practically prohibitive.

But this condition did not exist for long. The automatic air brake soon appeared. This was not only a great improvement over the older methods in points of rapidity and uniformity in the application of the brakes, but was a long step in advance as a safety appliance, the brakes being applied automatically by any accident causing a break in the piping system.

This was the last radical change in the principles of brake operation. Since then the improvements have been along the line of increasing the rapidity power and flexibility of operation of this automatic system, examples of which are thoroughly familiar to you all in the quick-action, high speed, and the more recent quick service, graduated release and quick re-charging air brake systems.

It might be noted in passing that the quick action automatic brake appeared just after the extensive series of air brake tests made by the M. C. B. Association at Burlington in 1886 and 1887, which had resulted in a decision that the operation of train brakes by compressed air, as then accomplished, was attended by such limitations in point of rapidity of application as to make the handling of fifty-car trains without danger to lading or equipment almost an impossibility. In spite of the natural reluctance of railroad men to adopt electrical control of the brakes, it was almost generally conceded that this was the only solution of the problem. How well it was solved without departing from purely pneumatic operation you well know. The improvements which have followed may seem of less importance, but a stage in the art of train operation has been reached, where the slightest gain in power, speed, safety, or even convenience of operation counts for much, and is sought after with corresponding energy.

For a proper appreciation of the fundamental laws which govern any given operation, and in order to approach intelligently new problems which may present themselves as conditions change, it is always profitable to "take account of stock," and arrange in as orderly a fashion as may be the facts concerning the question in hand with which we are familiar. It was with this in mind that the paper which I am honored in being permitted to present before you this evening was written. It is an attempt to express and illustrate certain physical laws, particularly those relating to friction, as clearly and concisely as possible, and to apply them to a study of the phenomena observed in the stopping of a train. Much which follows may seem to most of you elemental, but your patience with this is craved for the sake of the clearness of treatment which it is hoped will be gained thereby.

When a train is brought to rest from a high speed the statement is often made that the brakes have stopped the train. And they have certainly had something to do with the stopping of the train, for without them the length of stop would undoubtedly have been somewhat longer. But there are many factors which enter into the operation of bringing a moving train to a standstill beside the brakes themselves. Some of these other factors are at once apparent when the problem is given thought, but some are not so evident.

First, it must be thoroughly understood that one, and only one, fundamental cause brings a moving train to rest. This is *friction*. Now the friction concerned in stopping a train is by no means confined to one place. We have friction between the moving parts within the train itself, between the train and the atmosphere (and this is astonishingly great at high speeds), between the brake shoes and the wheels, and between the wheels and the rails.

Let us consider the latter for a moment. It is this friction, between the wheels and the rails on which they roll, which is really the most important factor of all. Very often, however, it is entirely overlooked, and we say, "The brakes stopped the train." But suppose, for example, that there is absolutely no friction between the wheels and the rails. This may be easily imagined by supposing the rails to be made of ice. Would any amount of brake shoe pressure bring the train to a stop quickly?

Before going further it will be of advantage to review some of the laws of friction, and then see how they apply to the case in hand.

In the first place, *friction* is the name given to that property of the surfaces of all bodies which resists the motion of one surface along another. Friction resists motion, and frictional resistance must, therefore, act in a direction opposite to the motion which exists, or would exist, were there no resistance to motion. We know that a block of iron may be slid along the polished top of a table easier than if the table were covered with coarse sand-paper. Furthermore, we know that if the table were covered with a thin film of oil, it would be easier still to move the block. And again, it would be easier to move a block of ten pounds weight than one weighing 100 pounds. So we see that the force required to move the block depends upon the *nature of the surfaces in contact* and the *weight to be moved.* If we have a block weighing 100 pounds in the form of a cube four feet on an edge, it will be no easier to move, other things being equal, than a cube ten feet on an edge and weighing the same amount. In other words, within certain limits the area of the surfaces in contact has no effect upon the amount of force required to slide the surfaces relatively to each other. When we deal with extremely heavy pressures per unit of area, the crushing strength of the material may be exceeded, and the nature of the surfaces in contact changed. In such cases the friction between these surfaces is correspondingly changed. Again, under very light pressures, we find that the force required to cause motion does depend upon the areas in contact. In such cases *adhesion* constitutes the larger part of the force which resists motion. A familiar instance of the force of adhesion is the resistance offered to the separation of two very smooth and plane surfaces, especially if well oiled, after having been pressed together. This resists the pulling apart of the surfaces as well as the sliding of one along the other, and depends largely on the area of the surfaces in contact.

To return to our block weighing 100 pounds, we notice that when we move it along the table it is easier to keep it going, after it is in motion, than it was to start it. Suppose a force of thirty pounds pushing on the block is required to just move it. After it has been started, a force of, say, twenty pounds may be sufficient to keep it in motion. The only difference in the two cases is that at first the block was at rest, while now it is in motion. It is plain that there must be a difference between the friction of rest and the friction of motion and consequently the former is known as *static friction* and the latter as *kinetic friction.*

We have seen that thirty pounds or the weight of the block multiplied by 0.3 was just able to move it. The number (0.3) is called the coefficient of friction, which we may define as the proportion or percentage of the weight or (where the two surfaces are held together by external pressure, as in the case of a brake shoe and wheel) of the force acting, which must be exerted in order to just overcome the frictional resistance. A coefficient in general is a number, constant for a given substance or condition and used to multiply one factor under consideration in order to obtain another desired factor. In the case of the block under consideration, a force of thirty pounds was required to overcome the frictional force resisting motion, and move the weight of 100 pounds. We see at once that to get the *force of friction,* we must, in this case, multiply the *weight acting* by 0.3; 100 x 0.3 = 30 pounds. Here, then, we call the number 0.3 the coefficient of friction, and 30 pounds the frictional resistance or force of friction. In the above instance 0.3 is the coefficient of Static Friction and 0.2 the coefficient of Kinetic Friction. The general rule may then be expressed thus:

Weight or force acting x coefficient of friction = force required to just move or just keep in motion, according to which coefficient is used.

The coefficient of friction is different for different materials in contact, and for different conditions of the same surfaces in contact. Suppose the table to be covered with coarse sand-paper. It may take a force of 50 pounds to move the block. The coefficient of friction is then 0.5 On the polished surface it took 30 pounds, the coefficient of friction being then 0.3. If we thoroughly grease the top of the table a force of 20 pounds may be sufficient to move the 100 pound weight. The coefficient of friction is then 0.2. So the coefficient of friction and, consequently, the frictional resistance, varies with the nature and condition of the surfaces. This is by far the most important and firmly established of the laws of friction, and has been reviewed, perhaps at undue length, in order that the fundamental principles involved in what follows may be constantly kept in mind.

The case of a car wheel rolling on a rail is slightly different from that just referred to, but we may consider that the point in contact with the rail is, *at that instant,* at rest so far as the rail is concerned. For, at each successive instant a new portion of the tire comes in contact with the rail. This part of the tire surface, for the moment during which it is on the rail, is not moving with reference to the rail. Consequently, the friction which prevents the wheel from sliding along the rail is not the friction of motion, but the friction of rest; that is, between the wheel and the rail we have to do with static friction. This may be most clearly seen in photographs showing a wheel rolling along the ground or on a rail. The part of the wheel near the point of contact with the surface over which it rolls is clearly and sharply defined, while the upper part of the wheel is blurred, showing that the point in contact with the ground or rail was at rest relatively to the camera.

The case is different when we come to the brake shoe, for here the wheel is always moving on the brake shoe, and we have always to do with the friction of motion or kinetic friction. As we have just seen the coefficient of friction in this case is always less, and as a rule it is very much less, than the coefficient of static friction.

We now approach the question of wheel sliding, and for a thorough comprehension of this a careful analysis of what occurs must be made step by step.

Suppose the brakes to be applied with a light pressure. This pressure multiplied by the coefficient of friction (kinetic) between the brake shoe and wheel gives the frictional force acting with a tendency to stop the rotation of the wheel. But the weight on the wheel multiplied by the *static* coefficient of friction between wheel and rail gives the frictional force resisting the tendency of the wheel to stop rotating, or, as we say, slide. A little thought will make it clear that as we increase the pressure on the brake shoe the frictional force tending to stop the rotation of the wheel increases, and that this increase in retarding frictional force will continue, as the pressure is increased, until the point is reached where this frictional force at the shoe becomes equal to the frictional force (static) between the wheel and the rail. Then the slightest increase in brake shoe pressure makes the frictional force acting to stop the wheel rotating the greater, and naturally it must then stop rotating. The condition of things is now entirely changed. The wheels are locked and are sliding along the rails. What have we now between wheel and rail? Evidently sliding or kinetic friction, where before it was static friction.

But we have just seen that up to the point of sliding a retarding force was being exerted by the brake shoes, which, when the point of sliding was reached, equaled the static frictional resistance between wheel and rail. Now, with the wheels sliding, a retarding force is being exerted only between the wheels and rails, equal to the kinetic frictional resistance between the wheels and the rails on which they slide, which, as we have already seen, is very much less than is the case when the wheels roll without sliding. Therefore, our retarding force is greatly decreased by the sliding of the wheels and the distance required in which to make the stop is correspondingly lengthened. We have thus arrived at the answer to the question so often asked, "Why is the distance traversed in stopping a train so greatly increased if the wheels slide during the stop, instead of continuing to roll?" It is plain that if the brakes are to be most effective in bringing the train to a stop the wheels must not slide; and the greater the resistance to sliding, due to the friction between the wheels and rails, the greater is the retarding force which may be exerted at the brake shoe and the shorter is the stop.

Another point frequently misunderstood or lost sight of is the relation between the brake shoe pressure and the weight carried by the wheel on which it acts, and in particular the amount of brake shoe pressure required to slide a wheel. In order to avoid complications let us imagine the wheel to slide at once, that is, as soon as the pressure is applied. What relation existed between the forces at the instant of sliding, or, in

other words, what made the wheels slide? The fact is that THE WHEELS SLIDE BECAUSE THE WEIGHT ON THE WHEEL X COEFFICIENT OF FRICTION (STATIC) BETWEEN WHEEL AND RAIL IS LESS THAN THE PRESSURE ON THE BRAKE SHOE X COEFFICIENT OF FRICTION (KINETIC) BETWEEN THE SHOE AND THE WHEEL. They do *not* slide because of the *coefficient of friction alone*, or because of the *pressure* alone, but according to the product of these two, *namely, the total frictional force,* is greater at the shoe than at the rail. Let us take an example which will illustrate just what is meant.

Suppose we have a car weighing 80,000 pounds having four wheel trucks. Each wheel supports a load of 10,000 pounds. An average value for the static coefficient of friction between the wheel and rail under ordinary conditions is .20. It may run as high as .30 or as low as .15, according to the condition of the rail. Calling the coefficient of friction .20 the total frictional resistance to sliding between wheel and rail is 10,000 x .20 or 2,000 pounds. This is then the force which must be overcome if the wheels are to be made to slide.

At 60 miles per hour the coefficient of friction between brake shoe and wheel is about .07. Suppose the braking power on our 80,000 pound car to be 90 per cent. of its weight. We have then a total braking power, in pounds, of .90 x 80,000, or 72,000 pounds, which gives a brake shoe pressure for each shoe, there being 8 shoes of 72,000 ÷ 8 = 9,000 pounds.

The retarding frictional force is then, as we have seen, the pressure x the coefficient of friction, or 9,000 x .07 = 630 pounds. We have then 630 pounds acting to stop the rotation of the wheel and 2,000 pounds acting to prevent it from being slid. We shall expect it to continue to revolve under these conditions, and for some time; in fact, until the condition of 630 pounds trying to overcome 2,000 pounds changes materially.

But it is asked, "What changes must take place in order to slide the wheels? and what changes of condition can take place?" From what has been said it is plain that the wheel can only slide when the total frictional force between brake shoe and wheel exceeds that between wheel and rail. Notice the expression "total frictional force," not "coefficient of friction." This is the one necessary and sufficient condition required to slide the wheel. Two possibilities are evident. The friction between the wheel and rail may decrease, which would occur if the wheel should suddenly come upon a greasy rail surface or if the pressure on the wheel is relieved due to the tilting of the car body, truck or similar causes, and cause the wheel to slide. Such cases will not be considered, as we assume a straight, level track with a uniform condition of rail surface. The only place left where any change may occur is between the brake shoe and wheel. To this then we must confine our attention. To slide the wheel, then, the total frictional force between brake shoe and wheel must increase until it becomes greater than that between the wheel and the rail, as has been already explained. This can occur in only two ways. Either the brake shoe pressure must increase or the coefficient friction (kinetic) between brake shoe and wheel must increase.

Taking the case cited above, if we consider .07 as the coefficient of kinetic friction at 60 miles per hour, the brake shoe pressure required to slide the wheel would be 2,000 ÷ .07, or approximately 28,500 pounds. This means a braking power, total, of 28,500 x 8=228,000 pounds, which is 285 per cent. braking power. Yet an 80,000 pound car can hardly be found braking at over 90 per cent. Apparently we might increase our braking power very considerably and still be in no danger of sliding the wheels.

But this is only half the story. We have seen how much the brake shoe pressure must be increased before sliding will occur. On the other hand, the coefficient of friction may increase, and so the wheels be slid, even with the same brake shoe pressure as before of 9,000 pounds. In order to do this the coefficient of friction must be equal to 2,000 ÷ 9,000, or .22. This may seem large when compared with .07, the average value for a speed of 60 miles per hour, but the fact has now become well established that the coefficient of kinetic friction between brake shoe and wheel is very different at different speeds. At 60 miles per hour the average value for this coefficient of friction is about .07, while at 30 miles per hour it is about .16, and at 10 miles per hour, about .24. We can now see what would happen in the case we have been considering. Although at the start, running 60 miles per hour, we had only 630 pounds retarding force attempting to overcome 2,000 pounds tending to prevent sliding (often called the "adhesion" of the wheel to the rail), yet at 10 miles per hour we would have 9,000 x .24 or 2,160 pounds retarding force at the brake shoe, which is more than enough to slide the wheels.

So we may not hasten to increase our brake shoe pressure or per cent. braking power without careful consideration. And upon investigation we do find still further factors which have an influence tending to modify this rapid increase in coefficient of friction due to decreasing speed. These may be briefly comprehended in the term, "the time element." While it is impossible to go fully into the interesting and complicated changes which the friction between the brake shoe and wheel undergoes during the time in which the surfaces continue in contact it may be said that tests have fully demonstrated that the heating, wearing away and polishing of the surfaces in contact have, as time goes on, a constantly increasing influence tending to reduce the coefficient of friction; the lubricating effect of the molten particles, the roller-like action of the larger particles which become torn off during violent and prolonged rubbing, and the smoothing and polishing of the surfaces, where melting or abrasion does not take place, all these tend to off-set, and may often considerably reduce the tendency for the coefficient of friction to increase as the relative speed of the two surfaces in contact diminishes. The retarding effect of the brake shoe pressure at any instant depends, therefore, on the sum total of these opposing influences at that instant. Numerous experiments which have been made along this line show that under ordinary conditions the increase in coefficient of brake shoe friction and consequent increase in retarding force, which takes place as the speed is decreased, is the predominating influence, and that the retarding

effect of a given brake shoe pressure increases, as a whole, as the speed diminishes. But recent tests have further demonstrated that this increase in retarding force, due to the increase in the coefficient of brake shoe friction as the speed decreases, is considerably less than has heretofore been supposed, and that under modern conditions of heavy pressures per square inch of brake shoe surface, high speeds, and so on, the "time element" effect may become equal to and thus neutralize the increase in the coefficient of friction due to decreasing speed. Under such conditions the coefficient of friction is the same at the end as at the beginning of the stop. This is modified by the degree of hardness of the brake shoe.

Having thus far been concerned with the kind of forces which operate to bring a moving train to a standstill, and the ways in which these forces act to produce the desired effect, it now remains to obtain some idea of the magnitude of the forces involved. This may be done by simple, yet exceedingly instructive consideration of the energy created and destroyed in the process of bringing a train up to speed and in making a stop. First, what must be done before a train can attain a speed of, say, 65 miles per hour?

We know that all matter is, as we say, inert; that is, it has no power of itself to change its state, either of rest or motion. A stone will always remain where it lies, unless some force from the outside acts upon it and overcomes its natural or inherent tendency to remain without motion. Furthermore, a stone thrown into the air would go on forever were it not for external forces, such as the attraction of the earth, air resistance, or obstructions which may be in its path, which retard and finally stop its motion. This property of matter to remain at rest, if at rest, or to continue to move *uniformly,* if in motion, has been universally recognized as something as definitely a characteristic of all material bodies as is size, mass or hardness, and it is called the *inertia* of the body.

To start a train then its inertia must be overcome, and in addition the very considerable frictional resistances between the moving parts within the train itself. Having the train once in motion a constantly increasing amount of force is required in order to continue to increase its speed, for we have just seen that instead of continuing to move uniformly the air and other frictional resistances would all tend to decrease its speed. All of the force which is required to overcome these resistances, and, in addition, constantly increase the speed of the train until it is moving at the rate of 65 miles per hour must come from the steam in the locomotive cylinders. Some of the energy developed here has disappeared in the form of heat, but the rest has been put into the train, constantly adding to its store of energy, until at 65 miles an hour the train has stored up within itself an amount of energy equal, in destructive power, to that contained in a huge magazine of gunpowder. Any one who has witnessed the effects of a "head-on" collision, even at slow speed, will bear witness to the truth of this statement.

In round numbers a train of five cars moving at the rate of 65 miles an hour possesses 150,000,000 foot pounds of energy, and if run against a solid wall the result would be the same as if it were allowed to fall to the earth from a height of about 150 feet.

But such a stop would not be considered as according to the best recommended practice, and as speeds of 65 or even 70 miles an hour are becoming by no means rare, some knowledge of how we may safely come to a stop is not only interesting, but of vital importance.

Let us imagine the train, moving as described above, to be stopped within say 1,400 feet. About 150,000,000 foot pounds of energy have been dissipated, harmlessly, and almost without the notice of those within the cars. Evidently some very powerful force has been at work to do this, and, as we have already seen, this is the force of *friction*. The natural frictional resistances of the air and the moving parts within the train would certainly have stopped the train in time, but it is plain that something more than these is required if a stop within any reasonable distance is to be made. The natural frictional resistances to the motion of the train are, therefore, artificially increased in such a case by means of some form of brake apparatus.

The power which is thus exerted may be roughly measured by the distance within which the moving train is brought to rest and its energy destroyed. In such a stop as described above more power has been used than the heaviest locomotive ever built is capable of exerting. The truth of this statement is evident when we remember that from five to six miles is required, even under the most favorable circumstances, for a locomotive to bring such a train up to a speed of 65 miles per hour, while the stop may be made within 1,400 feet, which is about 1-19 of that distance. Of course the frictional resistances existing outside of the brakes hindered the locomotive in accelerating the train and assisted the brakes in reducing its speed, but after all allowances are made it is clearly evident that the brakes have acted much more powerfully in stopping the train than did the locomotive in starting it. And this is just what we should expect when we remember that only one unit, namely, the locomotive, is concerned in starting the train, while not only the locomotive, but every car in the train is concerned in making the stop.

To start the train the total force exerted by the engine on the train at any time cannot exceed the frictional force between the driving wheels and the rails, sometimes called "adhesion," otherwise the drivers would slip and simply turn without moving the train ahead. Evidently this "adhesion" depends upon the weight on the drivers and the static coefficient of friction between the drivers and rails, just as in the case of the car wheel already considered. But when we make a stop each wheel in the train, as we have seen, may be retarded up to the limit set by the frictional resistance to motion between that particular wheel and the rail. Consequently, assuming that the coefficient of static friction between wheels and rails is the same throughout the train, the *retarding* power may be proportional to the weight of the entire train, while the *accelerating* power depends upon the weight on the engine drivers alone. This

explains at once the advantages of a multiple driving unit system, such as a train of all motor cars, as compared with the single driving unit system of locomotive and train. In reality, when the brakes are applied upon a moving locomotive and train the system is changed from a single accelerating unit to a multiple retarding unit system, which is much more powerful in the aggregate, as we have just seen, than is the former.

These are, it is believed, the most important of the fundamental principles upon which all correct reasoning in regard to the mechanical operation of trains must be based. Broadly stated, these principles reduce to the laws of friction and inertia, which act together to oppose any exterior force tending to produce motion from an original state of rest, or an increase in the speed of motion already existing, but which are opposed to each other as soon as the motion becomes constant or is retarded, in which cases friction tends to prevent the constant and uniform motion, which otherwise would exist, due to inertia. While an exhaustive or detailed treatment of the subject under consideration has not been attempted, and would not be profitable within the limits of a paper of this character, still it is hoped that the fundamental principles involved have been stated and illustrated with sufficient clearness and accuracy to enable any one interested in this subject to be assured of the foundations upon which his reasoning must be based. Beyond this he must rely upon his own accuracy of observation and deduction to carry him through to the complete and correct solution of whatever problem of this character he may be called upon to solve.

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Brake Operation and Manipulation in General Freight Service

With a Review of Some of the Causes and Conditions Which Produce Shocks and Break-in-Twos

BY

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BRAKE OPERATION AND MANIPULATION IN GENERAL FREIGHT SERVICE, WITH A REVIEW OF SOME OF THE CAUSES AND CONDITIONS WHICH PRODUCE SHOCKS AND BREAK-IN-TWOS.

By W. V. Turner

In the design of any brake equipment the starting point is always the weight of the vehicle to which the brake is to be applied. Given the weight of the vehicle, the problem then reduces simply to choosing the proper size brake cylinder which, with a predetermined maximum brake cylinder pressure and leverage ratio, will give the desired percentage of braking power. The process is clearly a simple one when applied to any given car and the method of procedure applied to cars of various weights will insure uniformity of results. However, it must necessarily follow that a brake equipment designed in this way for one car will not be proper for another car of a different weight from the first. The greater the difference in the weights of the cars, the greater will be the difference in the equipments required.

Underlying this proposition are fixed principles to which we must work if the best results are to be obtained, and once a set is determined upon for any design they must be continued as uniformity is fundamentally important. Of course, it must not be understood that departures from a proper basis will render a design inoperative, but it will not be as good as it should be in increasing proportion as it departs from the true starting point.

First: The thing to be fixed upon is the percentage of braking power permissible.

Second: The cylinder pressure to be used as a basis for calculation.

Third: Either the leverage or the size of the brake cylinder to be used.

(If the size of cylinder is determined upon, this will fix the leverage; if the leverage is determined upon, this will fix the size of cylinder.)

Regarding the first consideration namely, percentage of braking power, experience has confirmed that 70 per cent of the light weight of car on 60 pounds cylinder pressure (60 per cent on 50 pounds cylinder pressure) is the practically perfect basis for a freight car, and for reasons that are too obvious to require statement; but it should be added that reason confirms experience.

Regarding the second: This is important in two respects 1st, that it must be an obtainable pressure, 2nd, that it is universally applicable and adopted.

Regarding the third: This resolves itself into the question of how many times the cylinder power can be multiplied in a practical way, and is determined by the possible "lost motion" of the car, and the permissible increase of piston travel due to shoe wear, as the greater the number of times the cylinder value is multiplied, the more quickly will shoe wear lengthen the travel of the brake piston.

With the exception of the strength of materials, no other factors enter into the design, but those cited are vital and *must* be considered, and cannot be slurred over, nor can any one of them be omitted from the consideration and allowed to fix itself, for all others are so intimately related that they may be termed the one law of brake design.

It is often thought that an increase or decrease of the brake pipe pressure carried affects the design, but this is not the case, as this will only increase or decrease the braking power in an exact ratio to the change of pressure.

Assuming that sound principles and good judgment have been employed in designing the fixed apparatus of an air brake, namely, the triple valve, reservoir, brake cylinder, etc., and that these operate perfectly as individual units, (particularly in the laboratory where no moving vehicles are to be considered and, consequently, neither variations in power developed in the different cylinders, nor difference in time complicate the results of manipulation). It is necessary before discussing the actual manipulation of the brake to point out some of the factors which affect the operation and the manipulation of the brakes on the train as a whole. These may so change the original design as to make smooth operation and manipulation impossible. It appears to be thought by many that the brake being automatic in its action should also

be automatic in compensating for any lack of knowledge or for neglect on the part of those who use it, but this is not the case, and is as impossible of accomplishment as to run a locomotive without steam. The operation of the brake is according to fixed laws and conditions over *which the engineer of all men has the least control.*

As an elaboration of the principal factors involved would take up more time than has been at my disposal since being called upon to give this paper, and, undoubtedly, more than is at our disposal this evening, I cannot do more than state them and summarize the effects.

Percentage of Braking.

First: The percentage of braking power, so called. This has ususally been figured at 70 per cent on the light weight of the car, and this is certainly sufficient for the car when empty, but manifestly is reduced for the load in ratio to the difference in the weight of the car when empty and the car and load together. For example: if the braking power of a 40,000 pound car of 100,000 lbs. capacity is 70 per cent when empty, it will be less than 19 per cent when loaded, and this for emergency applications.

Pressure.

Second: The cylinder pressure obtained in the designs. This is supposed to be uniform for any given reduction and if the proper cylinder volume is maintained, it will be approximately so, but if the cylinder volume varies on the different vehicles, the pressure obtained will correspondingly vary, being less than normal for increase of volume and greater than normal for decrease of volume. Moreover, it is intended in the design that a low cylinder pressure be obtained for light reductions and a high cylinder pressure for heavy reductions, and this is the natural result, but lack of maintenance often brings about the opposite to this, for if the cylinder volume is small, a very high pressure will be obtained with comparatively light reduction, while a low cylinder pressure will be obtained for a heavy one in a cylinder having a long piston travel, and to avoid the results contingent upon this requires a knowledge of conditions and the exercise of a judgment possessed only by the few.

Piston Travel.

Third: Piston travel is such a factor in brake operation that its variation varies every operation of the brake as far as the developing power is concerned, for not only is the piston travel responsible for the variation in the cylinder pressure pointed out above, but it also varies the time required to obtain the braking power expected to be developed from a given brake pipe reduction. In other words, it is possible to obtain several times the braking power on one car as compared with another, due only to variation in piston travel, and it does not require a very vivid imagination to picture what this means to brake manipulation as far as producing shocks are concerned and it will also be seen that this is a factor over which the engineer has absolutely no control. Moreover, this variation in piston travel may be such as to entirely change the percentage of braking power expected to be obtained from the design for a given reduction, thus causing excessive braking power on some cars and too little on others, which is both prolific of shocks, due to surging, and of flat wheels, due to cars being dragged or bumped "off their feet."

Time.

Fourth: The time element is a very serious factor as affecting both the application and release of the brakes. In applying the brakes the starting takes place very quickly throughout a short train, therefore, there is no running in or out of slack, and, conquently, little or no shock, but in the long train, there is a considerable interval of time between the starting of the brakes on the head end and rear end of the train. In fact, the brakes on the head end may have fully applied for the reduction before they commence to apply on the rear end of the train, and unless great care and judgment is exercised to prevent bunching of the train, very serious results are likely to occur when the brakes apply at the rear and the reaction of the draft gear can stretch the train. Again, the rise of cylinder pressure is very different in the long train than in a short one, for the cylinder pressure cannot rise at any greater rate than the brake pipe pressure is being reduced and as this varies with the length of train, particularly at the rear end, it will be seen that the time factor must be considered with every brake manipulation.

The difference in and effect of time as affecting brake applications are graphically illustrated by Figs. 1 to 9, inclusive, of the Appendix, in which also some of the characteristics of curves are pointed out.

As to the release of the brakes, the time element also must be taken into account, for, obviously, there must be an interval of time between the release of the brakes at the head and rear end. This is certain even where the reduction has not been made below the equalizing point, but when the equalizing point has been passed, this difference is increased to such an extent that the engineer very often opens the throttle and accelerates the head end of the train while retardation is still taking place at the rear, and this even after he has thought he had allowed time enough. If it is important that the train be stretched before brakes are applied, it is doubly so before the brakes are released.

The difference in and effect of time as affecting the release of the brakes are graphically illustrated by Figs. 11 to 15, inclusive, of the Appendix, in which also some of the characteristics of the curves are pointed out.

Loads and Empties.

Fifth: Perhaps the most serious factor involved in freight train control is that arising from hauling loads and empties mixed, and this without considering any of the other factors enumerated above, but when considered in conjunction with them, the situation is certainly more serious than most people seem to think. As was pointed out, the braking power varies inversely, as the load and as the cars are now designed to carry about three times their weight, it will be seen that while the brake shoe pressure remains the same as for the light car the percentage of braking power, so called, to weight, has been reduced to one-fourth of what it was or is on the light car. If now we consider what must be the result of difference in cylinder pressure obtained and the time in which it is obtained on the empty and loaded car, it will be seen that with the present equipment, the only salvation against shocks and break-in-twos is (1st) to keep the train stretched—(2nd) to make at least initial reduction light in order that only a low power will be developed until the slack has adjusted itself—and (3rd) under

no circumstances to release the brakes, unless the slack condition of the train permits, until a stop be made. The usual custom is to haul the loads ahead and the empties behind and this is certainly more proper than hauling the empties ahead and the loads behind, for in case of a shock, with the empties behind, the result is at worst a parting of the train, while with the loads behind, the result is a buckling, which will be disastrous, particularly on parallel track roads. A better method of hauling loads and empties in the same train is to alternate them; thus avoiding great differences of braking power, due to variation in weight of train at any section of the train. This, however, involves switching, etc., which renders such a method impracticable. A better method still is to haul loads and empties in different trains. This again is impracticable on many roads. Thus, the proposition reduces to one of proper inspection and maintenance, instruction and discipline, which involves considerable intelligence and experience, or failing this, the proposition reduces to a cheerful acceptance of the consequences.

For a graphical illustration of conditions existing by reason of loads and empties, long and short piston travel and differences in "braking power" designs, see Fig. 16 of the Appendix.

It will be seen that all these factors are so intimately related that one involves the other to a considerable degree with the possible exception of loads and empties. Therefore, any neglect of one affects the other and conversely any great thought or consideration of the one improves the other. This relationship existing and time being limited, it will probably serve the purpose to consider two of these factors only at greater length, namely,

First: As to piston travel.

Second: As to braking power most desirable for freight cars under present operating conditions.

Piston Travel.

Piston travel may be divided into theoretical (under certain conditions Standing Travel closely approximates the theoretical travel) and actual travel (as under running conditions the travel differs from that obtained when the vehicle is standing). The theoretical travel is that which the brake cylinder piston is allowed to move in order to give proper shoe clearance, plus the movement due to the

necessary difference between the diameter of the pins and holes. Thus the theoretical travel equals the shoe clearance times the total leverage plus the travel due to difference in the diameter of the pins and holes.

The actual travel is comprised of the above plus that resulting from lost motion due to loose fitting brasses, play between boxes and pedestals, brake beam deflection and unusual temporary strains; in fact, to anything that produces or increases lost motion. I wish particularly to call attention to the practice of hanging brake beams from what amounts to a spring suspension, that is, to the car body or the truck frame above the springs. In such cases the shoes are drawn toward the rail by the pull of the wheel with consequent lengthening of piston travel. This is a most serious evil and where it exists the piston travel must be quite frequently adjusted to compensate for shoe wear, or the brake piston will strike the cylinder head; and in any case where excessive "false" travel is likely to develop a very low ratio of leverage should be employed.

The difference between the actual and the theoretical travel is erroneously called "false" travel, which, serious as it is, receives less consideration than any other thing in car design.

The theoretical piston travel is commonly called Standing Travel, and is defined as the distance the brake cylinder piston is forced outward in applying the brakes when the car *is not in motion.*

The actual piston travel is generally called the Running Travel and is defined as the distance the brake cylinder piston travels outward in applying the brakes when the car *is in motion.*

In studying the effects of piston travel, it must be remembered that in any application of the brakes, the brake cylinder pressure obtained depends upon two things; the ratio between the volumes of the cylinder and auxiliary reservoir, and the amount of brake pipe reduction. If the brake pipe pressure is reduced 10 pounds, the auxiliary reservoir will be reduced 10 pounds (slightly over); and the 10 pounds from the auxiliary reservoir going into the brake cylinder will create there a pressure depending on the volume of the cylinder and connecting passages as compared with that of the auxiliary reservoir. But the auxiliary reservoir volume does not change, so we may say that of the two, the brake cylinder volume alone is responsible for the pressure obtained. Now that volume depends on the amount of piston travel, if the

latter is short, the volume is small, and the 10 pounds auxiliary reservoir air will create a higher brake cylinder pressure than if the piston travel was longer and the cylinder volume thereby greater.

In order to show what a great difference the variation of piston travel makes in brake cylinder pressure and braking power, we show in Figs. 19 and 20 curves showing the theoretical variation for an 8-inch by 12-inch freight cylinder with standard cast iron auxiliary reservoir, with 6-inch, 8-inch and 10-inch piston travel, for different brake pipe reductions. Fig. 19 shows the relative increase or decrease of *cylinder pressure* as piston travel is decreased or increased. For example, with a 6-inch piston travel a 10 lb. reduction gives 34 lbs. cylinder pressure; while, with 8-inch 23 lbs. and for 10-inch 16 lbs. is obtained. Difference enough, it will be seen, to make those concerned take notice. Fig. 20 gives the percentage that the results in *braking power* obtained with the 6-inch piston travel are greater than those with the 8-inch travel; also the percentage less resulting with 10-inch travel as compared with the 8-inch travel. These curves show what great and damaging variations of cylinder pressure and braking power result with the initial brake pipe reductions. For example, with a 10-pound reduction, the braking power developed with a 6-inch travel is 45 per cent greater than with an 8-inch travel; also a 10-inch travel gives 38 per cent less than an 8-inch travel. In practice, the cylinder pressures realized are two or three pounds less than shown on the curves, while the braking power is considerably less, due to the lost motion, friction, and elasticity of the foundation brake gear. These losses make the conditions even worse than shown in Fig. 20.

We give in Table 1 the results that would be obtained in service with a 10-pound brake pipe reduction were there no losses of any kind. As a matter of fact the results actually obtained in service will be from two to three pounds lower, on account of leakage, etc. The effective braking power is that which would be delivered at the brake shoes for the cylinder pressure given, assuming that the leverage is designed for 60 per cent braking power at 50 pound pressure, this percentage being now recommended in freight service for steel cars, or wooden cars with steel underframes. In practice, 8-inch piston travel is usually taken as standard for freight service.

Table 1.

Piston Travel	Cylinder Pressure	Effective Braking Power	Comparison with 8-inch Travel
4″	52½ lbs.	63 %	130 % greater
5″	41 lbs.	49 %	78 % "
* 6″	33 lbs.	39½%	44 % "
7″	27½ lbs.	33 %	20 % "
* 8″	23 lbs.	27½%	—
9″	19 lbs.	23 %	16½ % less
*10″	16 lbs.	19 %	31 % "
11″	13 lbs.	15½%	44 % "
12″	11 lbs.	13 %	53 % "

*See Figs. 19 and 20.

Brake cylinder pressure and braking power developed with an 8-inch by 12-inch cylinder, having 50 cu. in. clearance, and standard cast iron auxiliary reservoir, with a 10-pound brake pipe reduction, and different piston travel, no losses whatever being considered, nominal braking power being 60 per cent on 50 lbs. cylinder pressure.

Tables similar to this could be made for any other brake pipe reduction, showing a variation similar in character but different in amount, the latter being greatest for small brake pipe reductions. As a result, it will be readily seen that if in a train, some brake cylinders have long piston travel and some short, a very uneven braking power will be developed for any brake pipe reduction, which will cause some cars to be retarded more than others, from which shocks and unnecessary strains on draw bars will result.

The proper piston travel is that which will develop approximately 50 pounds cylinder pressure when the auxiliary reservoir and brake cylinder become equalized from an initial auxiliary reservoir pressure of 70 pounds. This cylinder pressure (50 pounds) will then be the limit for a full service application, and should be obtained simultaneously on all cars. In Table 2 we show approximately the pressures at which the cylinder and auxiliary reservoir above mentioned will become equalized for different piston travels, and the brake pipe reduction required to give these equalizations.

Table 2.

Equalization pressures and brake pipe reductions necessary to give them for the brake cylinder and auxiliary reservoir given in Table 1, with initial auxiliary reservoir pressure of 70 lbs. and different piston travel.

8-inch by 12-inch Cylinder and Cast Iron Auxiliary Reservoir.

Piston Travel	Equalization Pressure	Brake Pipe Reduction
4″	59 lbs.	11 lbs.
5″	57 lbs.	13 lbs.
* 6″	55 lbs.	15 lbs.
7″	53½ lbs.	16½ lbs.
* 8″	51½ lbs.	18½ lbs.
9″	50 lbs.	20 lbs.
*10″	49 lbs.	21½ lbs.
11″	47 lbs.	23 lbs.
12″	46 lbs.	24 lbs.

*See Figs. 19 and 20.

Particular attention should be given, in this table, to the large variation in brake pipe reductions, the short piston travels requireing a smaller reduction and equalizing at a higher pressure than in the case of longer travels. To illustrate the detrimental effects of having such conditions in a train, let us suppose that two freight cars are coupled together, each having a light weight of 35,000 pounds, each equipped with an 8-inch cylinder and cast iron auxiliary reservoir, and the first having a piston travel of 11 inches and the second of 5 inches. It is plain that if a full service application is required on these two cars, a brake pipe reduction of sufficient amount must be made to equalize brake cylinder and auxiliary reservoir on both cars, which in this case would be 23 pounds, although 13 pounds would be sufficient for the second car. Consequently, 10 pounds of brake pipe air is wasted from the second car, and it obtains a cylinder pressure of 57 pounds, while the first car only obtains 47 pounds; moreover, the higher pressure on the second car is obtained in less than six-tenths of the time that the lower pressure is obtained on the first car. That is, there was 57 lbs. in the brake cylinder of the first car mentioned at the time that only 20 lbs. was in the cylinder of the second car. Let us suppose these two cars to be arranged to deliver 60 per

cent of braking power with 50 pounds cylinder pressure; then 57 pounds represents 68½ per cent braking power, and 47 pounds represents 56½. 68½ per cent of 35,000 pounds is 24,000, and 56½ per cent is 20,000 pounds. As a result, the stopping power of the second car is 4,000 pounds greater than on the first, and if we assume a speed of 20 m. p. h. and a coefficient of friction of 20% (which will be a fair average for this condition) a draw-bar pull of about 800 pounds is maintained between the two cars throughout the stop, or until the release of the brakes. If the release is made before coming to a stop, the brake pipe pressure need only be raised about 1½ pounds to cause the first car brakes to start to release, while it must be raised about 12 pounds before the second car brakes start to release. The first car, having a comparatively low cylinder pressure, would probably fully release before the second car started to, resulting in a draw-bar pull for a short time proportional to the *entire braking power* of the second car, or, in this case, about 4,800 pounds. This belated release is often, but incorrectly, called "a slow release"; while that on the first car would be termed "a quick release"; as a matter of fact, if the two cylinders started to release at the same time from the same pressure, they would take an equal time to accomplish it. The fault lies, not in the brake apparatus, but in the improper adjustment of the foundation brake gear.

But still another condition might arise. Suppose a 14-pound brake pipe reduction should be made; the second car would equalize at 57 pounds, or 68½ per cent—24,000 lbs. braking power, while the first car would only have a cylinder pressure of 24 pounds, the latter representing 29 per cent. braking power, or 10,000 pounds retarding effect. In this case, the draw-bar pull between the two cars during the application is about *2,800 pounds*, an amount which would be sufficient for the first car to bring the second, the latter loaded with 100,000 pounds of freight, from a standstill to 25 miles per hour in one minute.

From these considerations, it is clear that the best operation of the brakes can only be secured by maintaining a uniform piston travel upon all cars. The increase in the slack of brake rigging due to the wearing away of the brake shoes, must be constantly watched and taken up by means provided in the brake rigging, thereby maintaining the piston travel as nearly uniform as pos-

sible. By far the best means for accomplishing this is to install, in all cases where possible, an automatic slack adjuster, so called. Where this is not done, proper inspection and adjustment must be made at sufficiently frequent intervals to prevent any material increase in piston travel. As this inspection and adjustment has to be made while the car or train is standing, it must be remembered that running travel in steam road service is generally about $1\frac{1}{2}$ inches to 2 inches longer than standing travel, so that if an 8-inch running travel is desired, the standing travel should be adjusted to about 6 inches. If slack adjuster (shoe wear compensator) is used, attachment should be made to the 8-inch hole in cylinder.

Piston travel should never be altered to obtain a certain shoe clearance. This should be done by using brake cylinder of proper size, and through proper proportioning of the foundation brake gear. When inserting new shoes to replace those worn out, the brake rigging should be slacked off first, and the piston travel adjusted properly after the new shoes are in place. If, for any reason, it becomes necessary to change the piston travel, the auxiliary reservoir must also be changed, so as to keep the relative volumes of brake cylinder and auxiliary reservoir the same as before, thus insuring the same equalizing pressure and corresponding pressures for given brake pipe reductions.

The question as to whether the piston travel should be adjusted when the car is light or loaded makes necessary the following statement: Whenever the brake beam hangers are suspended from the solid part of the truck (which is now the best and most general practice), it is immaterial whether the car is light or loaded. If the hangers are attached to the car body, the adjustment must be changed whenever the car goes from light to load, or vice versa, for the following reasons: If the adjustment is done when the car is loaded, full braking power is available when the greatest weight is being handled, while there is a possibility, when the car is light and the shoes are raised making the shoe clearance less, that the resulting decrease in piston travel may raise the cylinder pressure sufficiently to slide the wheels. On the other hand, if the adjustment is made when the car is light, and the shoes in their uppermost position, wheel sliding is avoided, but there is danger that, when loaded, the increase of shoe clearance

and piston travel may result in greatly reducing the efficiency of the brake, and possibly no braking power at all for light deductions, which condition might cause runaways and disaster.

It is clear that a uniform piston travel is most desirable. If the piston travel be unnecessarily long, the brake cylinder pressure is thereby reduced and the efficiency of the brakes correspondingly impaired; in addition, a greater quantity of compressed air is consumed in brake applications than would otherwise be necessary, thereby entailing greater demands upon the air compressor, with correspondingly increased wear and tear. If the piston travel be too short, it is apt to be accompanied by dragging of the brake shoes upon the wheels while the brakes are released, and by too high a brake cylinder pressure, with an accompanying liability of sliding wheels, and rough and sudden stops when the brakes are applied. Besides, with a constantly varying piston travel, the engineer is never sure what retarding effect will follow any certain brake pipe reduction, and he will lose confidence in the brake; he can not become as expert in its manipulation as if the operation was more uniform, which if proper installation has been made, becomes largely a question of piston travel.

Curves illustrating the foregoing are given in Figs. 17 to 20, inclusive, of the Appendix, as well as a brief explanation of some of the characteristics.

Braking Power.

When the Automatic Air Brake was being put to a practical application, that is, used for controlling trains, it was found that the amount of cylinder pressure and braking power obtained for a given reduction were very important factors to be considered. After considerable experience and experiment it was proven, even for the comparatively short trains of those days, that the highest permissible braking power should not greatly exceed 1 per cent per pound of cylinder pressure (e. g., 70 per cent on 60 lbs. cylinder pressure) if trains were to be handled without shocks in ordinary service operation, and also that the cylinder pressures obtained should not exceed $3\frac{1}{4}$ lbs. absolute, per pound of brake pipe reduction; in other words, the auxiliary reservoir and brake cylinder should equalize at 50 lbs. from 70 lbs. initial; gage pressures (65 lbs. minus 15 for piston displacement). Accordingly a nominal brak-

ing power of something less than 60 per cent. on 50 lbs. cylinder pressure was fixed upon as the proper braking power for freight cars and an auxiliary reservoir employed so proportioned as to give a proper brake cylinder pressure per pound of brake pipe or auxiliary reservoir reduction and a brake pipe pressure of 70 lbs. was fixed upon as the desired pressure from which to obtain the maximum service brake cylinder pressure, namely, 50 lbs. These principles, of course, implied that "all air" trains were being handled for the reason that the length of train is an important factor in producing shocks, as if only a few air brake cars were being used, the brakes could not be much of a factor in stretching the train. However, it became the custom to use only a number of the brakes in long trains, generally on the loads ahead, the brakes on the empties not being used. Therefore, it was largely immaterial, under this condition of operation, what nominal braking power was adopted for the empty cars, as, obviously, if the brakes were not used, they could not stretch the train when being hauled behind loads. It was during this period that some roads increased the braking powers of freight cars from 70 to as high as 85 per cent. based on 60 lbs. cylinder pressure, and, of course, the result when hauling empties behind loads, particularly on a level, did not manifest itself as they were generally behind the cars on which the brakes were being used. When, however, it became the rule to operate "all air trains" quite another set of conditions were created, for not only were the brakes used on empties but, as far as the operation of the brakes was concerned, the length of trains was doubled, which is a serious factor, as the interval of time in brake application, particularly when combined with great difference of braking power at the two ends of the train, permits of the slack actions that are responsible for shocks. Thus the braking power of the empty cars became quite a factor in the handling of trains, for, obviously, the greater the braking power of the empties as compared with the load for the same cylinder pressure obtained from the medium reduction, the greater would be the retardation of the empties over the loads with consequent shocks and possible break-in-twos, particularly if the slack was bunched when the brakes were applied. Because of these things, a return was made to the old rule of 60 per cent nominal braking power based on 50 lbs. cylinder pressure, and even this would be regarded as

too high, if means were available for properly taking care of the car when loaded. If the braking power is made very great on the empty cars an approach will be made to the bad practice which was responsible for so many break-in-twos when employed, namely, hauling passenger cars with the brakes in use on the rear end of a freight train, or, what is perhaps even worse, permitting empty freight cars with short piston travel to be hauled behind loads.

Another thing that should be kept in mind is that a vital element in handling long trains without shock is the uniformity of the braking power both in time and amount, and as there is no such thing as uniformity in the amount of braking power when we consider loaded and empty cars with long and short piston travel and the various percentages of nominal braking power employed, etc., nor of *time* when we consider that this is varied by length of train and brake pipe leaks, etc., it is important that we prevent the ill effects of these variations to as great a degree as possible, which can best be done by insuring that the braking power obtained be as low as controlling the loaded car will permit, and its attainment stretched over such a period of time by range of brake pipe reduction, as will make sudden and severe strains unlikely. This is not only desirable but possible from the fact that all the braking power needed for controlling the loaded cars, even on grades, can be obtained by increasing the brake pipe pressure, which increases the ultimate braking power on all cars alike and without in any way interfering with the flexibility of the brake, i. e., without giving severe braking power for the initial brake pipe reduction, which it is important to avoid until the slack has had time to adjust itself. Moreover, this increase of brake pipe pressure does not widen the gap, already too great, between the ordinary service braking effort of the loaded and empty cars, while to increase the braking power on the empty cars does this to a serious degree. In other words, it does exactly opposite to what good engineering requires and what we are endeavoring to do, namely, bring about a uniformity of braking power on the empty and loaded cars.

In this connection, we might also mention that when it was found necessary to increase the stopping power of passenger trains it was not done by increasing percentage of braking power per pound of cylinder pressure, which, to obtain the increase desired, would have destroyed the flexibility of service features of the brake,

but, by increasing the pressure carried, thereby obtaining a cylinder pressure sufficiently high to give the desired increase of braking power. If this was the necessary procedure with passenger trains, how much more so with the long freight trains where the time and slack elements are of a much more variable and serious nature.

To compare the relative gain on empty and loaded cars by the proposed increase in nominal percentage of braking power (and considering service operation only, as the question of uniformity mentioned above need not be considered in emergency) we may take the following example:

PRESENT STANDARD.		PROPOSED STANDARD.
70% on 60 lbs.	Nominal Braking Power	70% on 50 lbs.
58.5% on 50 lbs.	This is equivalent to	85% on 60 lbs.
40,000 lbs.	Car—Light Weight	40,000 lbs.
140,000 lbs.	Car—Loaded Weight	140,000 lbs.
	FOR FULL SERVICE APPLICATION.	
	(50 lbs. Cylinder Pressure Obtained.)	
58.5%	Braking Power—Light Car	70%
16.7%	Braking Power—Loaded Car.	20%
41.8%	Difference between braking power on loads and empties.	50%
	FOR 10-POUND REDUCTION.	
	(20 lbs. Cylinder Pressure Obtained.)	
23.5%	Braking Power—Light Car	28%
6.7%	Braking Power—Loaded Car	8%
16.8%	Difference between Braking Power on loads and empties.	20%

By raising brake pipe pressure to 90 lbs. instead of increasing nominal braking power to 70% on 50 lbs., as proposed, the service operation is not affected. That is, for reductions up to that which will produce a brake cylinder pressure of 50 lbs., the braking power is the same as at present. The obtainable or reserve power of the brake is considerably increased, however, since the service equalization pressure is increased from 50 lbs. to 65 lbs. which would give

76% Braking Power—Light Car.
21.7% Braking Power—Loaded Car.
54.3% Difference between Braking Power on loads and empties.

From the above it is seen that if we increase the braking power from 70% on 60 lbs. to 70% on 50 lbs. (85% on 60 lbs. cylinder pressure), it will result in a net gain of 11.5% braking power on the light car and 3.3% on the loaded car for a full service application—the difference between the braking power on loads and empties being increased from 41.8% to 50%. If the desired increase is obtained by leaving the nominal braking power the same as at present standard (70% on 60 lbs.) and increasing the brake pipe pressure carried from 70 lbs. to 90 lbs., for a full service application, the gain on the light car is 17.5% and on the loaded car 5%. It should further be noted that up to 50% (the service equalization pressure when 70 lbs. brake pipe pressure is carried), there is no difference in the braking power obtained for a given cylinder pressure. That is, by raising the brake pipe pressure to 90 lbs. the brake remains the same for ordinary service reductions, but the ultimate braking effort is advanced by 17.5% on the light car and 5% on the loaded car. While this, of course, results in a wider difference, (54.3%) between the braking power on the loads and empties, it should be remembered that this is for 15 lbs. higher brake cylinder pressure than that for which this difference under the proposed standard is only 4.3% lower. Furthermore, this difference can only be attained by a full service reduction, during the progress of which the slack has an opportunity to adjust itself harmlessly, and while by increasing the leverage, the difference, as pointed out above, obtains on all partial as well as full service reductions. Again by increasing the brake pipe pressure, the gain is available on all cars alike, gives a large reserve power, during ordinary service applications of the brake and requires only an adjustment of the feed valve to accomplish the same, while the benefits of an increased nominal percentage of braking power are obtained only on those cars whose levers have been changed accordingly.

Fig. 16 (see Appendix) illustrates graphically the difference in braking power on loaded and empty cars. Taking for example a 10-pound reduction with 8-inch piston travel and 70% braking power, you will note that while the braking power on the loaded car is less than 10%, it is more than 30% on the empty car, or in other words, over three times as great. If, however, we assume a condition which frequently occurs in actual service; that is long (or relatively long) piston travel on the loaded cars ahead, and

short (or relatively short) piston travel on the empty cars behind, etc., it will be seen at once by the chart that the variation in braking power between the loaded and empty portions of the train is very much emphasized. For instance, with the 10-pound reduction as mentioned, we have a braking power on the loaded portion of about 8%, while assuming for the sake of illustration a piston travel of 6 inches on the empty cars, we have a braking power of about 47% or almost six times as great. If, on the other hand, the higher braking power of 85% is employed, and a 10-pound reduction is made with normal piston travel, the braking power on the loaded car is but a trifle over 10%, whereas that on the empty car has been raised to 37½%. From this it will be seen that the increase in percentage on the empty car is far greater than that on the loaded car, which latter in fact is but trifling. Consequently, the difference between the two is greatly exaggerated.

In the case of unequal piston travel cited above, if the braking power were raised to 85%, that of the loaded car when a 10-pound reduction is made would be increased only from 8% to 9%, whereas that of the empty car would be increased only from 47% to 56%, the undesired difference in braking power being thereby greatly aggravated.

Use of Release and Running Positions.

I feel a few words should also be said regarding the use of release and running positions on the brake valves, for it is here that the engineer may start trouble, for with the high pressures and large main reservoirs and the long trains of today, it is very easy to overcharge the head end of the train as compared with the rear and with a short train to over charge it throughout as compared with the adjustment of the feed valve. Many detrimental effects result from this, such as stuck brakes, flat wheels, cracked wheels, undesired quick action and where successive applications are made, as in grade work, in the brakes on the head cars doing practically all the work.

Another result which I would like to impress upon all is that a great many engineers think that because the gage shows that the pressure has risen very rapidly, and higher than the auxiliary reservoir pressure is intended to be, that the brakes are released and consequently open the throttle, while, as a matter of fact,

this is a condition that exists only on the first few cars of the train, the pressure of the rear not having yet increased sufficiently to force the triple piston to release position. In fact, twenty-five cars back from the engine, it cannot be told from a gage whether the handle is in release or running position. With modern engine equipment, the brake valve should not be held in release position more than 15 seconds when releasing brakes is the object. The exceptions to this rule are when charging up a train, or under some conditions of grade work.

An inspection of Figs. 21 to 27, inclusive, of the Appendix, accompanied by a perusal of the explanation will demonstrate the importance of this phase of the subject.

It will be seen from what I have said that brake manipulation and operation in freight service involves more than the judgment of the engineer in moving the brake valve handle back and forth. In fact, much more is dependent upon the condition of the train and the brakes than upon the manipulation by the engineer. Nay, more, it will be seen that the conditions may often make judgment impossible and insure shocks and break-in-twos in spite of it. Comprehension and application should come *down* from the officials to the engineer and instruction and discipline *up* to the engineer through the car men and trainmen. Until this is done, we are trying to cure our troubles by pecking away at the effect instead of what is more logical and reasonable, namely, dealing with the cause.

In concluding this subject, I desire to mention some of the changed operating conditions which have made much more difficult the control of freight trains, then analyze a proposed change or two expected to improve conditions, after which offer a few suggestions, the adoption of which will greatly reduce shocks and break-in-twos.

First: Heavy and more powerful locomotives (often two of these used to a train)—increasing the difficulty of starting trains without shock—making long and heavy trains possible, this, self-evidently, making the control more difficult—also severe strains, are set up when the brakes are released on these heavy weights before it is possible to obtain the release of the brakes on the rear; also with freight trains bunching the slack (because the brakes on the engine, if in good order, will produce more retardation than

those of the cars), then when the brakes take hold on the cars at the rear (generally empties), or, if for any other reason, the slack runs out, shocks are likely to result. With passenger trains, the reverse is true, as the cars are always being retarded more than the engine, and therefore the train is stretched.

Second: Cars of greater capacity, therefore, greater weight, and this without corresponding increase of the light weight, thus reducing the braking power when loaded to a greater extent than with the older cars. This condition creates a greater difference in braking power between the forward and rear end of the train when we have loads ahead and empties behind.

Third: Different percentages of braking power, some roads using 70 per cent and others as high as 90 per cent of the light weight; others, again, intermediate percentages. These things all tend to make the braking power unequal (and, of course, the longer the train, the worse it will be, because the time element "cuts quite a figure"); so much so, that if we got together a combination of long trains—loads ahead—empties behind—(and if these empties have short piston travel, the situation is aggravated to a remarkable degree), high percentage of braking power—slow speed and brake application (particularly if made by an engineer who does not nor has not taken these things into consideration),—a break-in-two is to be expected.

Fourth: Different sizes of brake cylinders. And this has more effect than most people think. For one reason, because the total leverage will be varied by the weight of the car and size of cylinder, thus the piston travel, so important a factor with light or medium brake pipe reductions, will vary greatly for the same shoe wear—this is self-evident with cars under-cylindered or when equipped with brakes with which the service and emergency cylinder pressures are the same.

Fifth: Varying brake pipe pressure: This changes the time element, often resulting in a heavier or a lighter application than was intended.

Sixth: Varying brake pipe volume: Thus modifying the time of application and release; and this far beyond direct proportion. The effect of this will be seen when it is borne in mind that men who have been coupling up and handling a fixed and limited number of cars—therefore, an approximately constant volume—often

fail to release the rear brakes of a long train before opening the throttle, or take into consideration the length of time it takes to get the air out or back into the brake system of long trains.

Seventh: "All air trains," and from a train handling standpoint this is one of the most important factors, as no matter what the make-up of the train, the brakes must be cut in within certain limits, therefore, if the train is so made up that excessive and damaging retardation takes place at the rear, the scheme of cutting out every other brake cannot be resorted to, as was done on some roads until recently, where "all air trains" were being handled. (By "all air trains" is meant that the brake pipe is charged with air from the engine to the rear of caboose.) Not only this, but it is plain that more knowledge, greater skill and constant thought is required on the part of all concerned to deal with conditions so variable as those involved in the make-up and the means of controlling the trains today. In other words, the human equation is more of a factor than ever before. This, I am happy to say, is beginning to be realized, and soon, I hope, many will be convinced that more consideration must be given to the condition under which the brake operates, if the results due to lack of consideration are to be avoided, for it is a fact that there are proper and improper conditions for the brake as for other mechanical devices, and there is more to it than simply attaching it to a car.

Eighth: In this connection, it may be well to mention that the many different styles of draft rigging have quite a bearing on the matter of shocks in trains; those possessing the greatest dissipating power with no recoil being, in my opinion, very necessary to meet the conditions of today, as the brakes and engineers can hardly be expected to compensate for all the changes that have taken place.

Ninth: Other things might be mentioned and elaborated upon —such as a greater number of parallel tracks, more yards and the frequency of trains, but I think the foregoing will help keep in mind the complexity of the problem when what follows is being considered.

Many schemes are proposed to alleviate these troubles; good, bad and indifferent, most of them bad because they do not touch the root of the matter. In one detail they are nearly alike, viz., in beginning with the engineer, while here is where they should end.

The brake is a good servant, but a bad master, and it becomes rebellious when contending with impossible conditions and is somewhat sensitive to neglect.

A quasi-plausible scheme actually put in effect on a great railroad for a time (a short time only for the remedy was worse than the disease) and recently considered by another, was to reduce the pressure carried in the brake system to 50 or 55 pounds. There were three advantages to be gained by this, so it was said:

(1) That the braking power would not be so great for a service reduction and, therefore, that the severity of the shocks and break-in-twos would be reduced. This, however, would only hold true for heavy reductions, as, for instance, a 10-pound reduction would give the same cylinder pressure whether the brake pipe pressure be 70 lbs. or 55 lbs., other things being equal. And, as the shocks and break-in-twos will usually occur, if at all, by the time a 10-pound reduction has been made, it is plain that reducing the pressure would be of no help in this case; this, of course, applies to service applications.

(2) That undesired quick-action will occur less frequently. This, however, will not necessarily follow, as, while undesired quick action due to friction caused by pressure on the slide valve may be reduced, yet undesired quick action due to slowness of reduction will be increased. Therefore, the gain in one direction is offset by the loss in the other, and I believe more than offset. Moreover, there should be no undesired quick action with 70 lbs. brake pipe pressure carried, and if there is, it can be corrected much more effectively by keeping the apparatus in a workable condition than by reducing the efficiency of the brake; which means in the last analysis its abandonment.

(3) That in the event *of undesired* quick action the maximum braking power possible to obtain with the lower pressure will be less than with the higher; and here we have the only reason that is even plausible. But even this can only be granted when it is assumed that we are compelled to choose between two evils, viz., (1) air brakes improperly maintained and operated and, (2) a lower efficiency of the brake both in service and emergency applications. It is self-evident that the brake will be less efficient with an emergency application, but it may be necessary to point out that for service applications not only would the braking power

of an equalized application be less, but the reserve for partial applications would be much less in one case than in the other. In other words, where with 55 lbs. brake pipe pressure the operator would have to use a reduction that would produce equalization to control his train and therefore eliminate any reserve and make a stop impossible; on the other hand, with the higher pressure the same reduction would give him the same train control and leave a reserve braking power equal to that already obtained, thereby making a stop possible if called for.

The above, I believe, covers all the arguments that can be advanced in favor of the lower pressure, and the analysis shows that they are by no means sound and certainly not sufficiently decisive to warrant the change. It may be said (but certainly not advanced as a reason) that 55 lbs. will control an empty train more effectively than 70 lbs. will a loaded train, and this may be granted but it does not follow from this that the empty train with 70 lbs. has any surplus of control, and until this is proven, it would not appear wise to lower the braking power of the empty train simply because the loaded train is under-braked.

Moreover, *these other things* should be considered; that it will be difficult to secure the change of pressure when changing an engine from an empty train to a loaded train, and vice versa, and no doubt you would often find the loaded train carrying 55 lbs. and the empty train 70 lbs. of brake pipe pressure, and particularly I believe you would find that once the engineers were led to believe that 55 lbs. was a panacea for their troubles, it would be difficult to prevent their carrying the lower pressure when they should carry the higher—especially where the train is made up of loads and empties; also it should be considered whether it is trains composed of all empties that are breaking in two in the great majority of cases. I am of the opinion that you would find that it is where a long string of empties are behind loads that this occurs; if this is so, even a consideration of 55 lbs. cannot be permitted.

Another scheme actually put in practice by some roads is to put up the percentage of braking power on empty cars. This is done ostensibly to increase the braking power for the cars when loaded. There *may* be some excuse for roads doing this who have heavy grades to negotiate, for perhaps they consider it a choice between

putting up with break-in-twos or risking run-aways on the grades, or perhaps they have empties one way and loads the other, as for example the D. I. & R. 125 per cent, or perhaps again they are wise and do not haul empties and loads in the same train, knowing that by increasing the braking power on the empties they have made this more riskly and impracticable than ever before. However, the other roads have to handle the cars, so somebody gets the effect.

As it is unequal braking power that is responsible for shocks, anything that tends to this is pertinent to the question of train control. Therefore, the analysis of this practice, on pages 15 to 21, is in order. It must be understood that as some look at it, it is a choice of two evils—braking power too low for grades, or too high for empties behind loads—but if they increase the braking power some one is going to have greater difficulty in smoothly controlling some classes of trains.

In this connection I may also point out that general recommendations and instructions apply to general conditions; particular and specific conditions requiring and permitting considerable modification of such general recommendations to suit the case, and it is only with an intimate knowledge of and with particular reference to such cases that one can be specific.

There are other schemes no more effective or practical than this, their chief virtue being a *desire* to find some way to reduce shocks and break-in-twos. As these undoubtedly arise from unequal braking power in different parts of the train, which may be temporary, as, for instance, the brakes applying more quickly or with higher cylinder pressure at the head end of the train than at the rear; or permanently, as, for instance, when there are loads ahead and empties with short piston travel at the rear, I will point out that shocks or break-in-twos may be greatly reduced by:

(1) Forbidding the use of the straight air brake of the engine to bunch the slack of the train before applying the automatic brake. I am aware that you will quote Westinghouse Instruction Books against this rule, but these instructions, as well as many others, were given to suit conditions very different from those of today. It is a self-evident fact that when conditions change, old rules and instructions become obsolete, or must be changed to suit the new conditions. A slight review of the instruction regarding the

use of straight air to bunch the slack gently, may be sufficient to demonstrate this. This instruction given when only part "air trains" were the rule, was necessary, as if the brakes were applied on the braked cars before the slack was in from the unbraked cars behind the shock was sometimes equal to a collision. Now, if the slack is bunched with an "all air train," particularly with empties at the rear, the running out of the slack, as the brakes take hold at the rear, often results in a break-in-two and certainly in a shock which is damaging to both equipment and lading.

Personally, I doubt the advisability of using straight air at all for train control, as so much judgment and care is required to use it when and where it will do good and not harm. I mean now for making stops or slow-downs—for if it is applied heavily, a collision is often the result—if applied and released and the throttle opened, while the cars are bunching or still bunched at the rear, a break-in-two is in order. Of course, there are critical speeds and conditions when damage is more likely than at other times. Straight air on the engine is of great value when used at the proper time and place, but it was not intended to take the place of the automatic brake in controlling trains, nor to be used because *unfair conditions* impair the efficiency of the automatic brake.

(2) By placing loads at the head of the train and shortening the piston travel, and the empties behind and lengthening the piston travel,—bringing about a greater difference in cylinder pressure for graduating applications and thereby securing greater equality of braking power between loads and empties; at the same time the emergency pressure will be only slightly altered.

(3) Alternating loads and empties.

(4) Applying the brakes before the slack is bunched as, for instance, before the steam is shut off.

(5) Instructing engineers not to use emergency applications unless actual emergency exists; not, for instance, to consider every switch, water-tank, or coal shute as an emergency zone and apply the brakes accordingly.

(6) Not to use heavy initial service reductions, unless speed is low and stop intended.

(7) Do whatever is necessary and possible to secure uniform application of brakes.

(8) Do all possible to insure that it is the engineer that is controlling the application of the brakes and not the brake pipe leakage, and in general that the brakes are maintained in such condition that the anticipated operation is possible and obtained. Give the engineer a chance.

(9) Avoid, if possible, applying or releasing brakes when pasing over "Hog-backs" or round curves.

(10) Avoid releasing the brakes before the brakes have ceased to apply during a reduction.

(11) Avoid, whenever possible, applying the brakes again after a release, while the brake pipe pressure is higher at the head end than at the rear, in other words, equilibrium of pressure should be established throughout the train, as otherwise the head brakes will apply and those at the rear will not—therefore, the cars may be bunched and if the brakes at the next reduction take hold, this in conjunction with the recoil of springs will produce severe shocks.

(12) Avoid releasing brakes at speeds below ten miles per hour unless the locomotive is equipped with "ET" or the forward cars with K" triple valves, as otherwise brakes releasing at the head end permit the retardation still existing at the rear to stretch the train—sometimes beyond the strength of the car connections.

(13) Avoid, whenever possible, having too many cars at the rear which are levered for a high braking power, as for instance, cars (of which there are many in service) upon which the braking power is calculated at 90% on 60 lbs. cylinder pressure—it is obvious that this aggravates the already existing inequality of braking power between loads and empties and is in effect the same as attaching so many passenger cars to the rear end of a freight train, which no one who expected smooth operation would do, unless the brakes on these rear cars were alternately cut out.

(14) Locate the places where accidents of the kind under consideration most often occur and advise extra precautions, for, undoubtedly, you will find that there are certain track or signal conditions, which, in conjunction with an application or release of the brakes (to say nothing of the starting of trains), tend to produce shocks, and this, added to the already numerous factors tending in the same direction, often result in a "break-in-two." I think you will find that a number of your men are cognizant of this fact and have these places pretty well "spotted" and are governed accord-

ingly and, therefore, do not have near the trouble that some others do who either cannot reason back from effect to cause or are careless. To these latter a little information and advice may mean a close approach to the results obtained by others who learn by experience. I think I can illustrate what I mean by this paragraph by calling to your mind how necessary it is that an engineer, new to a division, become acquainted with the track, etc., before the best results can be expected. In other words, other things being equal, his proficiency depends largely upon his knowing the condition under which he operates.

(15) At speeds of over 20 miles per hour make a light preliminary reduction, followed by continuous heavy reductions when speed is reduced to, say, 8 miles per hour and stop intended. At low speeds, when stop is intended, make a continuous full reduction. The reason for this is to keep the slack bunched as the brake will naturally be applying with greater power on the head end than at the rear, therefore, tending to keep a steady push toward the engine.

(16) If slow-down only is desired, it is better to make a light reduction, far enough back, than a heavy one to accomplish the same result in less distance; in the former case, when the release is made (even if at slow speed) there should not be braking power enough to cause shock, while in the latter case the reverse is true.

(17) Enforce the rule that with long trains the engine must be cut off from the train whenever an accurate stop is imperative, as for coal and water, and insist that, after again coupling to the train that sufficient time be allowed for the brakes to release before trying to start the train.

(18) A terminal inspection that will discover and send to the repair track all cars with defects particularly of draft gear, that are likely to cause trouble on the road. There is no doubt that a great number of break-in-twos are due to defective brakes and draft gear being allowed to leave terminals, and it is hardly a question whether it is wiser to take chances than to adopt a safer method. Of course it is only a matter of time before the inevitable happens, but each thinks it possible that the car will reach the next terminal. Plainly, as long as chances are taken in these matters, even the best of care on the part of those operating the train on the road, cannot prevent a great many break-in-twos.

As stated, the difference in braking power is held to be the cause of shocks, etc., and the foregoing include at once the reason why and how it can, in a large measure, be overcome and uniformity more closely approached. It is plain that to do this involves both effort, expense and inconvenience, but my railroad experience taught me this was unavoidable and to be expected in railroad operation, and I may say that in the matter under consideration, what has been outlined permits of a choice between what *exists* and *what we desire*, to determine which the benefits versus the cost will be the governing consideration.

In conclusion, it may be well to state that the cause of break-in-twos may be traced to the method of handling the brakes—to the condition and class of draft gear and brake equipment—to the make-up of the train and the kind of train service—it being understood that the human equation is a qualifying factor at all times. All these causes taken singly or collectively are such at times as to make a break-in-two difficult if not impossible to avoid.

"Break-in-twos" are caused by greater braking power at the rear than at the forward part of the train. This class of break-in-two often causes much inconvenience and some loss, but as it is a separation and not a collision the danger of serious accident is not great, unless following trains are too close.

"Buckling" is caused by greater braking power at the forward end of the train than at the rear. This occurrence not only means inconvenience and loss but that the danger of serious accident to both the train to which it occurs and to others of either direction is very great, as the cars may be scattered over the different tracks.

I have gone into this part of the subject somewhat fully, if not completely, because I should at least do so sufficiently, to permit of your weighing both sides of the question.

The number of things mentioned show the complexity of the problem and many may say that no one can take all these things into consideration. This may be so, but they exist and must be dealt with as a condition and not a theory, and in proportion as they are taken into consideration will improvement be made, and, what is also important, the responsibility will be placed where it belongs, which is the first step toward desired results.

It will be seen that there are four elements involved in every brake operation, namely: 1st, time: 2nd, amount of reduction or

change of pressure in the brake pipe: 3rd, amount of cylinder pressure obtained, and, 4th, percentage of braking power. Only one of these is fixed, viz.—the percentage of braking power. That is, a given pressure in the cylinder gives a certain braking power; all the rest are variable. For instance, the time required to reduce the brake pipe pressure a certain amount is varied by increasing or decreasing the length of the train because this changes the volume of air in the brake pipe. The amount of reduction required to obtain a given cylinder pressure is varied by the ratio of the reservoir to the brake cylinder and the cylinder pressure obtained from a given decrease in reservoir pressure is varied by the ratio of the brake cylinder to the reservoir, which ratio is varied by an increase or decrease of piston travel, as this in effect increases or decreases the size of the brake cylinder. Plainly, then, all these elements must be kept in mind when considering any problem involving train control and it is only by knowing the relationship existing between the different elements that the cause of the results obtained can be deduced.

The control of trains has become a much more complicated problem than heretofore, much knowledge of all the conditions involved is necessary, and the best talent available will be taxed to the limit to get the most economical efficiency, and yet, strange as it may seem, these things are realized only by the few.

The air brake has advanced in the past year or two from being considered chiefly a safety appliance that was required by law to be applied, to an absolute necessity in the handling of freight and passenger trains, and its operation must be properly understood to make it a dividend earning asset.

THE PRESIDENT: The speaker wishes to know if you prefer to ask questions now, or if you want to ask the questions as he throws the slides upon the screen.

A. J. COTA (C. B. & Q): I believe it would be the best plan to have him put on the slides first.

MR. TURNER: In the paper read it was pointed out, among other things, that the percentage of braking power, the cylinder pressures obtained, the effect of varying piston travel, and the time element were very important factors and modify both the operation and the manipulation of the brake. These elements and their effects can be shown by curves and charts even better than in actual operation and a number of these are referred to in the text.

The majority of these curves and charts are traced from indicator cards. The indicators used are essentially similar to steam cylinder indicators, but in addition have an electrical attachment connected to a clock which registers the time—the time of the commencement of the experiment and its duration being registered simultaneously throughout the whole train, consequently, we not only have the time for the whole experiment, but also the differences in time between any similar operation throughout the train. In other words, we know the time of any given operation at any part of the train. Other of these curves are plotted from calculations, as they are simply questions of proportion, and one of their values is that they serve to show how important is the maintaining of the proper proportions and that in so far as they fail from what is proper the operation is adversely affected.

THE PRESIDENT: We would be glad to have you ask such questions as you may have in mind and we will give Mr. Turner an opportunity to reply to them before the minutes are published.

MR. W. E. SYMONS (C. G. W. Ry.): Owing to the lateness of the hour, and the fact that Mr. Turner has talked for a couple of hours, giving us a very interesting paper, and I might say, a highly scientific lecture, I think it would be an imposition to ask any questions here tonight that would involve further discussion. There are one or two points which occurred to me that I would like to mention, with the suggestion that Mr. Turner be furnished a copy of the questions asked (and on which I would like permission to amplify), so that he can reply by letter in his closure.

Question 1. In the earlier part of Mr. Turner's paper he mentioned the fact that the braking efficiency of cars varied from 100 per cent to as low as 44 per cent, or, we might say, a range of difference in efficiency of 56 per cent, and while the details were not given as to just all of the causes that might contribute to this, yet it might occur to some that the different makes of brakes and different types of the same make, might have a little something to do with this condition.

It was also suggested by the author, that the switching of cars to certain parts of the train would minimize this trouble to a great extent, and while this is true, yet under present operating conditions this plan may be considered impossible, and of course it is necessarily incumbent upon the motive power officers to take care

of the brake equipment in such a manner, that no matter what distribution is made of this diversity of types and conditions we should get practically what might be called average results, and if there is anything that Mr. Turner can tell us in his closure that would throw additional light on the best thing to do to the brakes now on our cars (aside from suggesting the switching of the cars around), that would be a very good thing for the motive power department and mechanical officers to have to work upon.

Question 2. Another point in connection with that same question was, where the piston travel varied, causing a wide range of difference in cylinder pressure. My recollection is the author said that a great deal of trouble resulted from this inequality of piston travel, and the consequent difference in pressure of the brake cylinder was largely due to the faulty location or arrangement of the foundation of the brakes. Now, if I am right in that, I want to ask the author if he would kindly explain, if that was the fault of the railway companies in applying brakes to cars that they build, or in making repairs, or is it a fault in the designs furnished by the air brake builders? I am assuming that all brakes are applied according to prints furnished by the Air Brake people, therefore, if the foundation of the brake is faulty, or in any manner affects their operation or the proper equalization of pressure, then the fault may be due to the design, and not chargeable to the Railroad Companies.

Question 3. Another question has occurred to me in connection with this matter that I do not think the author mentioned. With some systems of levers, or brake arrangements, the brake rod lies pretty well out to the side of the car, in fact, on some trucks with side bearings spaced 60″ radius, the brake rod lies next to the side bearings, and sometimes on the outside, with the upper end of the brake lever almost in line with the side bearings, and in rounding curve, with this brake rod on outside of the curve, I would like to ask if this will have the effect of shortening the rod, particularly on rounding a very sharp curve? If that is true, is it then not a fact that this might exert some influence on the derailment of a car. Assuming that curve elevation was arranged for a high rate of speed, in which case the centrifugal force would result in the equilibrium of the car body, but the train moved at a slow rate of speed around the curve, allowing the cars to lean heavy on the inside of the curve, and bearing hard on the inside side bearing, if

that was the case, and the brake rod was on the outside, and this condition resulted in shortening the rod thus placing more strain on it than when the car was on the straight track, would it not have the effect of assisting the leading outside flange of the truck wheel in climbing the rail. Would not this combination assist somewhat in a derailment which otherwise might not occur if the train was going at a higher rate of speed, or was on a straight track?

Question 4. Another point in connection with friction draft gears, which possess, as we all admit, many good points, but just what effect they would have, or what percentage of effect in the elimination of damage to cars or contents, the author did not state, and I would be glad if he would elaborate a little on that, if he so disposed, particularly on the type of draft gear, spring or friction that is considered most efficient in service and economical in repairs.

In the matter of sending cars to the rip track when they need repairs, that point is a very good one, and while of course it would result in a highly improved condition of the brakes, I rather suspect if that were followed out strictly, we would have to stop a great many important trains with high grade freight when they really could go forward, and while I think the instruction or advice given to railways is very good, yet I am inclined to think the railroads would hardly be able to carry this out, so long as the present method of handling cars is in vogue that we now tolerate in switching yards, which results in much damage to draft gear in general. Still, if the author feels that recommendation can be carried out, I would be very glad if he would elaborate on that point.

There are a number of other points that are quite important, but I feel, owing to the lateness of the hour I have mentioned all I should, and in justice to the author, I would not ask him to reply to them this evening.

PROF. L. E. ENDSLEY (Purdue University): I appreciate the difficulty experienced by the author in preparing a paper like this in so short a time, and I move you, Mr. President, that the Club extend a vote of thanks to Mr. Turner for this very excellent paper.

MR. TURNER, *Answer No.* 1: Replying to the first question asked by Mr. Symons, I may say that the great differences in braking power may come from each or a combination of several causes, namely: difference between empty and loaded weight of cars, different standards of braking power on different railroads, and some-

times even by the same railroads, variations in piston travel, brake cylinder leakage, length of train, and the use of different makes of brakes, in which the auxiliary reservoir and brake cylinder proportions are different and in some of which the service amd emergency brake cylinder pressures are the same. All of these factors are dealt with at considerable length in the body of the paper and various suggestions as to their elimination in some cases and a minimizing of their detrimental effects in others are given, and finally it is stated that the officials have the choice of correcting some of these evils as they do others in connection with railroad management, or of letting them exist, which, however, will not be done when it is realized how profitable an air brake in good working order may be made, particularly as this will eliminate from the loss side of the account the cause of troubles and damage always inseparable from mechanical devices not in proper working order. I respectfully refer those who require a more complete answer to Mr. Symons' question to those pages of the paper covering this subject and to the curves and charts in the appendix.

Answer No. 2: In many cases the variation in cylinder pressure on different cars, or on the same car at different times, for the same amount of brake pipe reduction is due to improper foundation brake gear design, making it impossible to obtain or maintain the piston travel required by the auxiliary reservoir volume (which, it may be needless to say, is the same for all brake cylinders of the same diameter in steam railroad practice), which necessarily means that the stroke of the piston must be uniform if the same and proper cylinder pressure is to be obtained. In this connection I may say that very few designs for foundation brake gear are furnished by the Westinghouse Air Brake Company—in many cases the general practice being to build the car without any particular reference to the foundation brake gear and then put it on as may best or easiest be done, nor was this so important when the brake was looked upon as a mere safety device, but since it (the brake) is now essential to control trains in ordinary every day operation, it is also essential that greater consideration be given to foundation brake gear design, installation and general maintenance. However, the chief causes of differences in cylinder pressure are neglect to adjust piston travel for brake shoe wear and the hanging of the brake beams on the car body side of the springs, which permits the piston travel to change

according to whether the car is empty or loaded, and also very materially increases the piston travel by the creeping of the shoes toward the rail when the brakes are applied, due to pull of the wheel on the shoe. This latter is one of the worst forms of false travel. This question is also covered more in detail in the text of the paper and by the curves and charts.

Answer No. 3: As it was not the purpose of the writer of the paper to go quite so far as we are carried by this question, an answer is not exactly called for, still I might be pardoned for saying that inferentially this bears out the statements made in the answer to Question No. 2, that foundation brake gear designs are sometimes bad.

Another reason for not answering this question is that the answer is contained in the question, for Mr. Symons has so well outlined the stresses set up by such an installation that there can be no doubt of the bad effect of such a design of the brake, or that, under certain conditions, the tendency is to derail the car.

Answer No. 4: The writer mentioned draft gear in one paragraph of the paper and then only to call attention to the fact that in some cases the cause of a break-in-two could be found in the draft gear, and, wherever the draft gear is too weak for the stresses to which it may be subjected, or is weakened by usage, it is likely to give way under conditions where it would not occur if of proper strength or design. Moreover, break-in-twos often occur where a draft gear is employed that absorbs energy instead of dissipating it, as is the case with spring gear, and this will be all the more appreciated when it is considered that the recoil is given back in the form of a jerk instead of a buff—a jerk being much more likely to part a train than a buff.

As the draft gear situation is before us in many papers, pamphlets and discussions, the writer thought it was sufficient to merely call attention to draft gear as one of the elements involved in the general question, and, therefore, to avoid repetition respectfully refers those interested to literature dealing with draft gear problems and designs.

As to sending cars to the repair track, I may say that nine-tenths of the work required to eliminate air brake troubles and obtain proper efficiency can be done without sending cars to the repair shop. Instructions to inspectors and carmen as to what to do in the way of stopping brake pipe, brake cylinder and retaining valve

leaks and adjusting piston travel and insistence upon its being done is one of the chief requirements, and all this work can be done with the train in the yard. True, it will take some little time, but the delays will be nothing compared with those now occurring on the road and, of course, the damage to equipment and lading will be eliminated proportionately. Next, engineers should be taught that there is some difference between handling a long train with all the brakes cut in and a short train; also a difference in handling all empties, all loads or mixed trains; also that conditions are different now that we have "all air" trains that when only the brake on a few cars were used and the remainder not. In fact, the manipulation required now, in many instances, is the reverse of what it used to be. For example, the old rule was to bunch the slack before applying the brakes—the present rule is to avoid this. Again, with small pumps and small main reservoirs and low pressures, the full release position could be used with impunity, but with large compressors, large main reservoirs and the high pressures of today (which have a reason for their existence), the full release position must be handled with considerable thought of the consequences.

Again, with the brakes used only on a few cars, and these loads, and the slack of the cars behind the air cars bunched by use of straight air on the engine, or other means, a *heavy* reduction was not only permissible, but proper, but now with the air operative throughout the train and empties behind, a heavy reduction is likely to break the train in two, because of the disparity in retarding force between the loaded and empty cars. In other words, the initial reduction now made should be light in order that the cylinder pressure obtained on the empty cars should not create such retardation at the rear as would break the train in two. It will be seen that none of these things involve sending cars to the "rip" track. Of course, there are some cases where this is necessary and it should be done, but this is not so universally necessary as is generally thought. In fact, I believe it is the impression that this is necessary, which is responsible for the failure to make the slight repairs and compensations required for wear and tear between terminals. The defects are generally small individually, but the potentiality for trouble in an aggregation of these is great. We are not limited to two horns of the dilemma as implied in the interrogation of whether or not we shall send cars to the "rip" track, for it is not

a question whether we send all or none, as we may send only those that require such repairs as cannot rapidly and quickly be made in the yard, repairing such others where they stand.

In conclusion, I may say that it was not the writer's intention to usurp the prerogative of the railroad official and say what can or what cannot be done, nor how things should be done, but to point out what is required to efficiently control freight trains and what is responsible for failure to get such control—the pleasure of devising the means and method being left to those concerned, as well as the choice of having things as they are, or as they ought to be.

MR. TURNER: I should like to say one word relative to this evening, and that is, that I thank those who have listened to the paper, which was rather technical in places. There were a great many points brought up in connection with the work required to make it clear, for an evening like this, a great deal of elaboration, therefore I feel that the paper will be much more beneficial when printed than it has been tonight. I know when I was studying those points over from the practical point of view, that it took me more time to figure out all there was in it; it did not take very much time to put it on paper, but it takes a lot of time to figure out all that is involved in it, and therefore the effort was not so much to write a paper that would be satisfactory or create an impression this evening, but something that would bear looking into. The fact is, gentlemen, the conditions enumerated in that paper lie before us and they must be dealt with, and if any of you feel like backing up the engineer or the conditions that exist, the best thing to do is to take that paper and see whether you can remedy it, or whether you will put up with the trouble cheerfully.

THE PRESIDENT: I think it is entirely unnecessary that the author of the paper should offer any apology. Personally I feel, and I am sure the rest of the members feel that it is a paper we shall feel proud of having presented to us.

It has been regularly moved and seconded that a vote of thanks be extended to the author of this very excellent paper. All in favor signify by saying "Aye." Contrary "No." It is unanimous.

Adjourned.

APPENDIX

After the paper was read certain curves and charts were thrown upon a screen by means of a stereopticon, and their characteristics explained and the effects of these in train control discussed. Obviously, such explanation, even though reproduced verbatim would be unintelligible as a pointer was employed to designate this or that line or figure, which cannot be reproduced in print. It has, therefore, been thought best to give a brief explanation of the charts instead of trying to reproduce the stereopticon lecture, cross references being given in the text of the paper to this explanation and from this back to the subject matter these are intended to supplement and emphasize.

Until very recently air brake questions have been settled strictly according to individual opinion—there being no standard of reference except the individual who was supposed to be an authority in air brake matters. Now these questions are settled by a reference to a standard written by the apparatus itself; viz. the indicator card registering what actually takes place during the action in question. Consequently, we have but one answer and that the correct one. To a question involving like conditions, it is no uncommon thing to get several different answers from the different authorities. Any one of them may be right and all of them may be wrong, for each authority is probably assuming different conditions, as but few questions are asked which are complete, or if the question is complete, it is so general in character that a large volume would be required to completely answer it. For instance, What will cause a slid flat wheel?

Fig. 1 illustrates graphically, when compared with Figures 5 and 6, how length of train affects the application of the brake both as regards pressure and time. It will be seen that with the old type of triple valve very little cylinder pressure was obtained on any of the cars and that there was an interval of 45 seconds between the application of the first and last brakes in the train. The curves for the "K" valve show that not only can the difference in time of application be overcome in a large degree, as here the interval between the first and last brakes was but 10 seconds, but also that a more effective cylinder pressure was obtained.

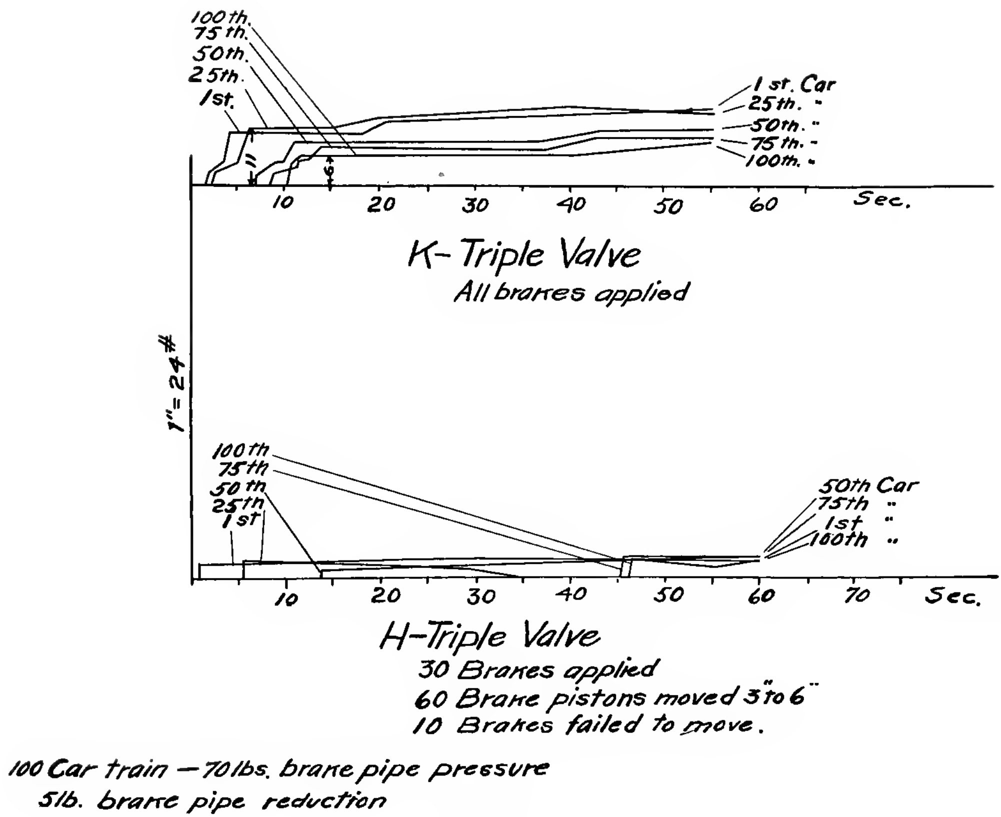

100th.
75th.
50th.
25th.
1st.
1st. Car
25th. "
50th. "
75th. "
100th. "
11
6
10 20 30 40 50 60 Sec.
K-Triple Valve
All brakes applied
1" = 24#
100th
75th
50th
25th
1st
50th Car
75th "
1st "
100th "
10 20 30 40 50 60 70 Sec.
H-Triple Valve
30 Brakes applied
60 Brake pistons moved 3" to 6"
10 Brakes failed to move.
100 Car train — 70 lbs. brake pipe pressure
5 lb. brake pipe reduction

FIG. 1.

Fig. 2 differs from Fig. 1 in that a 10 pound reduction instead of a 5 pound was made, and a comparison between the two sets of cylinder cards shows how much more effective and uniform in operation the brake is when the time element in the application is reduced to a minimum.

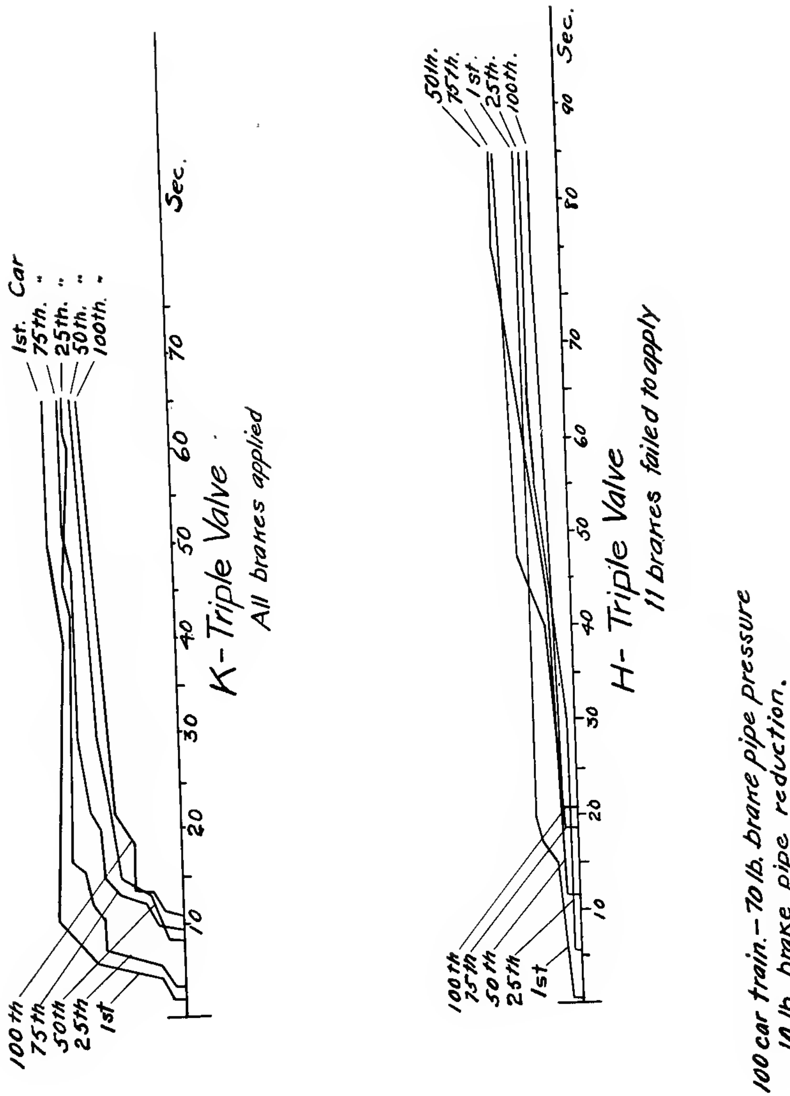

1st. Car
75th.
25th.
50th.
100th.
Sec.
K-Triple Valve
All brakes applied
100th
75th
50th
25th
1st
10
20
30
40
50
60
70
50th.
75th.
1st.
25th.
100th.
Sec.
10
20
30
40
50
60
70
80
90
H- Triple Valve
11 brakes failed to apply
100th
75th
50th
25th
1st
100 car train.— 70 lb. brake pipe pressure
10 lb. brake pipe reduction.

FIG. 2.

Fig. 3 differs from Fig. 2 in that the reduction was 15 pounds instead of 10 pounds.

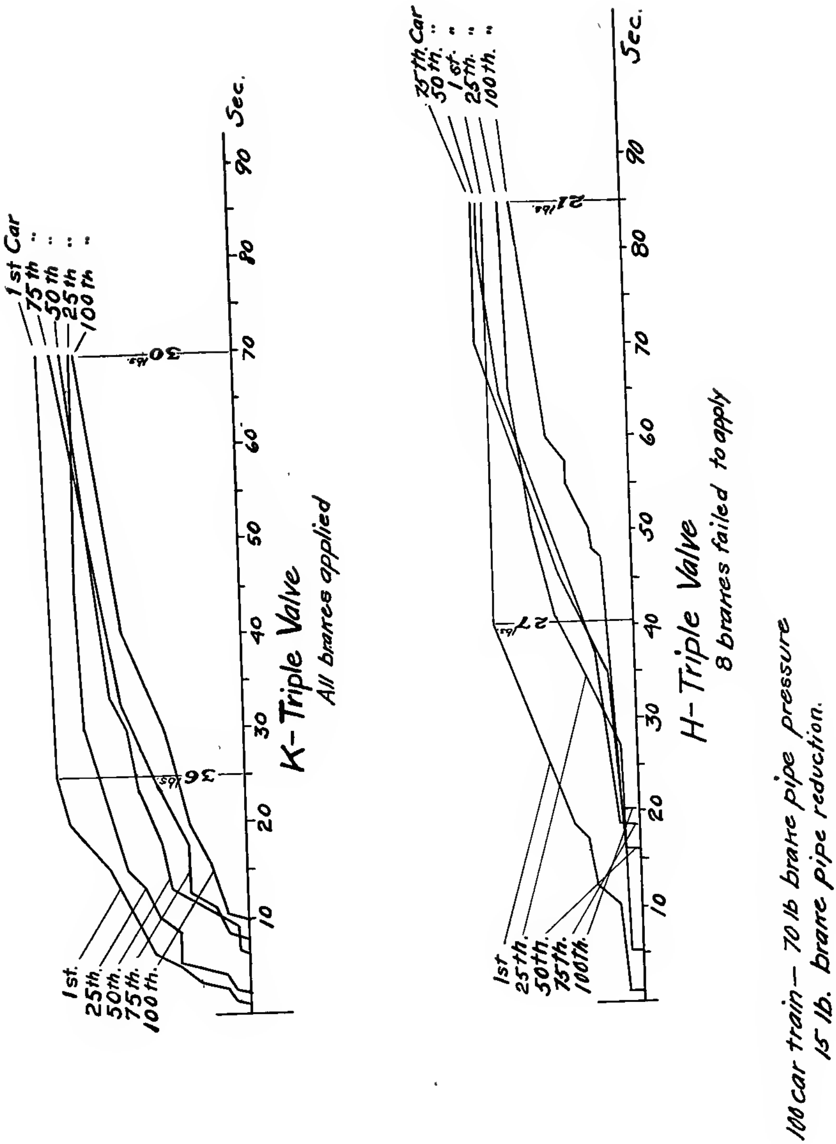

K-Triple Valve
All brakes applied
1 st Car
75 th "
50 th "
25 th "
100 th "
30 lbs.
36 lbs.
1 st.
25 th.
50 th.
75 th.
100 th.
Sec.
H-Triple Valve
8 brakes failed to apply
75 th. Car
50 th. "
1 st. "
25 th. "
100 th. "
21 lbs.
27 lbs.
1st
25th.
50th.
75th.
100th.
Sec.
100 car train— 70 lb brake pipe pressure
15 lb. brake pipe reduction.

FIG. 3.

Fig. 4 differs from Fig. 3 in that the reduction was 20 pounds by a full service application instead of 15 pounds. A glance at this set of charts will show that they are self-explanatory. As to operation effects—the difference in time and pressure can only be appreciated by those who have had experience in brake matters, or who are willing to be governed by those who have.

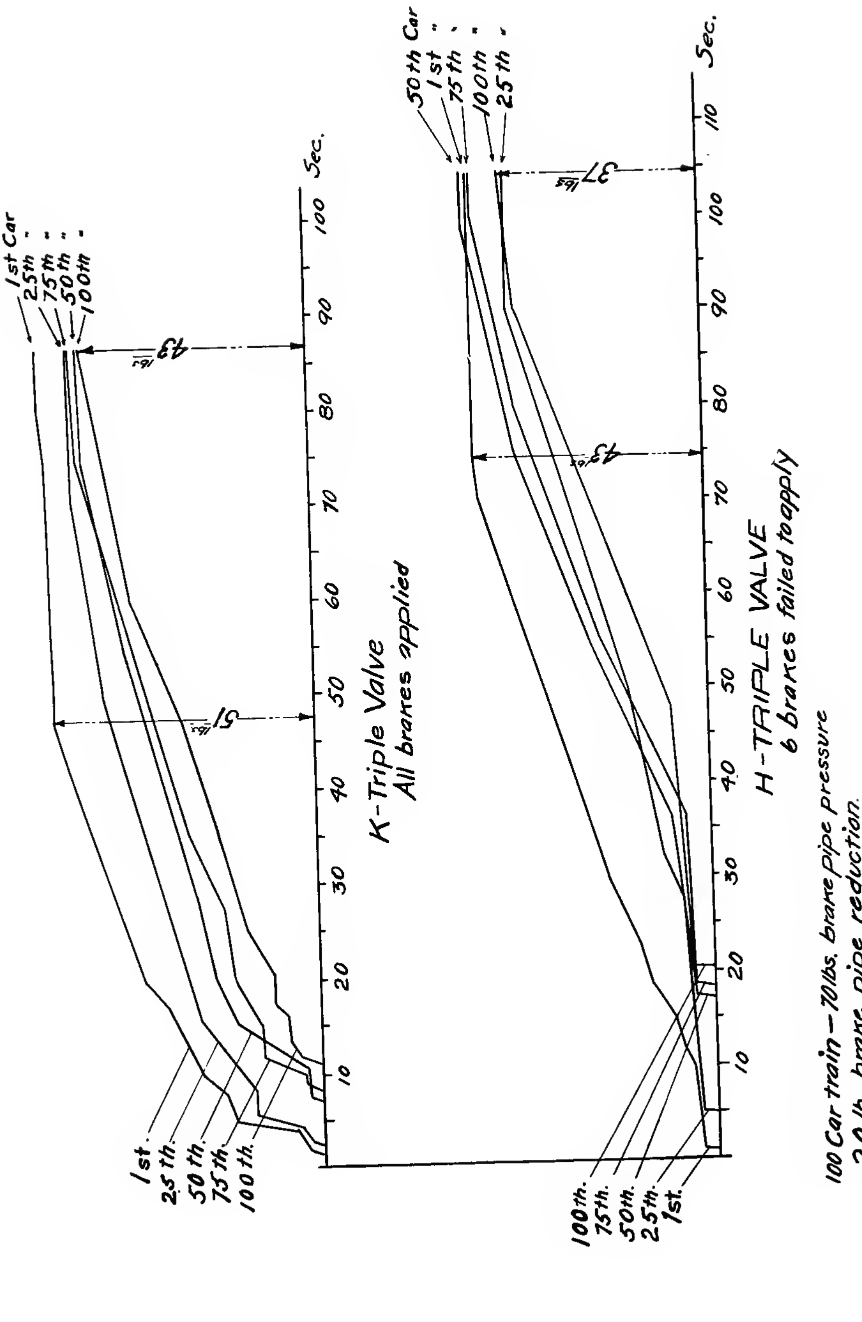
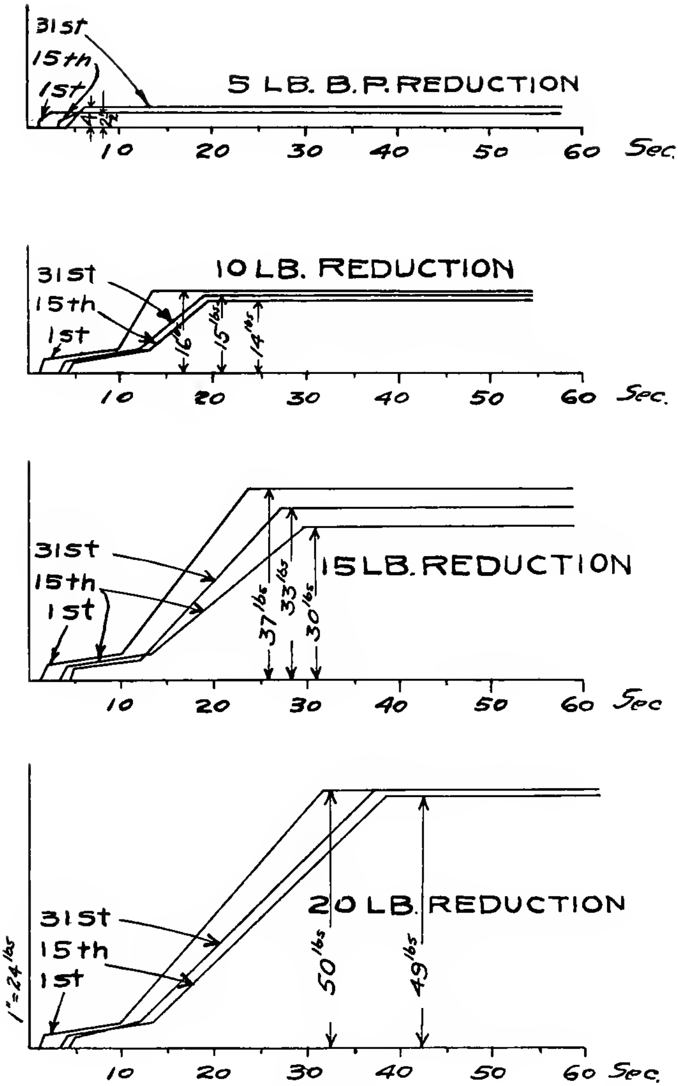

K-Triple Valve
All brakes applied
1st Car
25th "
75th "
50th "
100th "
43 lbs.
51 lbs.
1st.
25th.
50th.
75th.
100th.
Sec.
H-TRIPLE VALVE
6 brakes failed to apply
50th Car
1st "
75th "
100th "
25th "
37 lbs.
43 lbs.
100th.
75th.
50th.
25th.
1st.
Sec.
100 Car train—70 lbs. brake pipe pressure
20 lb. brake pipe reduction.

FIG. 4.

Fig. 5. The cylinder cards of this figure, when compared with Figs. 1 to 4 inclusive, illustrate what a great difference in time and pressure exists between a long and short train, as here the interval of time between the application of the first and last brakes was but 6 seconds as compared with 45 seconds with a 100-car train and same type of triple valve; while with a 20-pound reduction maximum cylinder pressure was obtained in about 35 seconds instead of 105 seconds with a 100-car train.



31st
15th
1st
5 LB. B.P. REDUCTION
10 20 30 40 50 60 Sec.
31st
15th
1st
10 LB. REDUCTION
16 lbs
15 lbs
14 lbs
10 20 30 40 50 60 Sec.
31st
15th
1st
15 LB. REDUCTION
37 lbs
33 lbs
30 lbs
10 20 30 40 50 60 Sec
1" = 24 lbs
31st
15th
1st
20 LB. REDUCTION
50 lbs
49 lbs
10 20 30 40 50 60 Sec.

Fig. 5.

Fig. 6 is similar to Fig. 5, except that the cards were made from the quick service triple valves. These curves show that the effect of brake pipe volume, due to length of train at the time of application, is less than with the old type of valve.

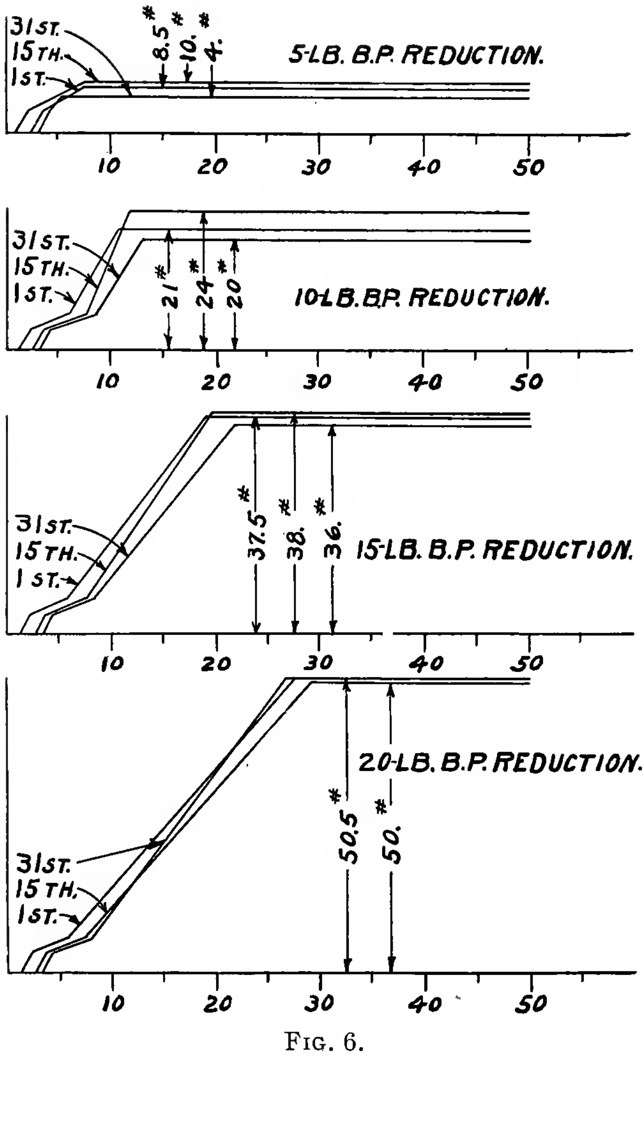

31ST.
15TH.
1ST.
8.5#
10.#
4.#
5-LB. B.P. REDUCTION.
10
20
30
40
50
31ST.
15TH.
1ST.
21#
24#
20#
10-LB. B.P. REDUCTION.
10
20
30
40
50
31ST.
15TH.
1ST.
37.5#
38.#
36.#
15-LB. B.P. REDUCTION.
10
20
30
40
50
20-LB. B.P. REDUCTION.
31ST.
15TH.
1ST.
50.5#
50.#
10
20
30
40
50

FIG. 6.

Fig. 7 illustrates the difference in time and pressure in the application of the brakes on the 1st, 25th and 50th cars. Not only is the rise of cylinder pressure shown, but also the rate of fall in brake pipe pressure, which will seem to be very slow on a train of even this length.

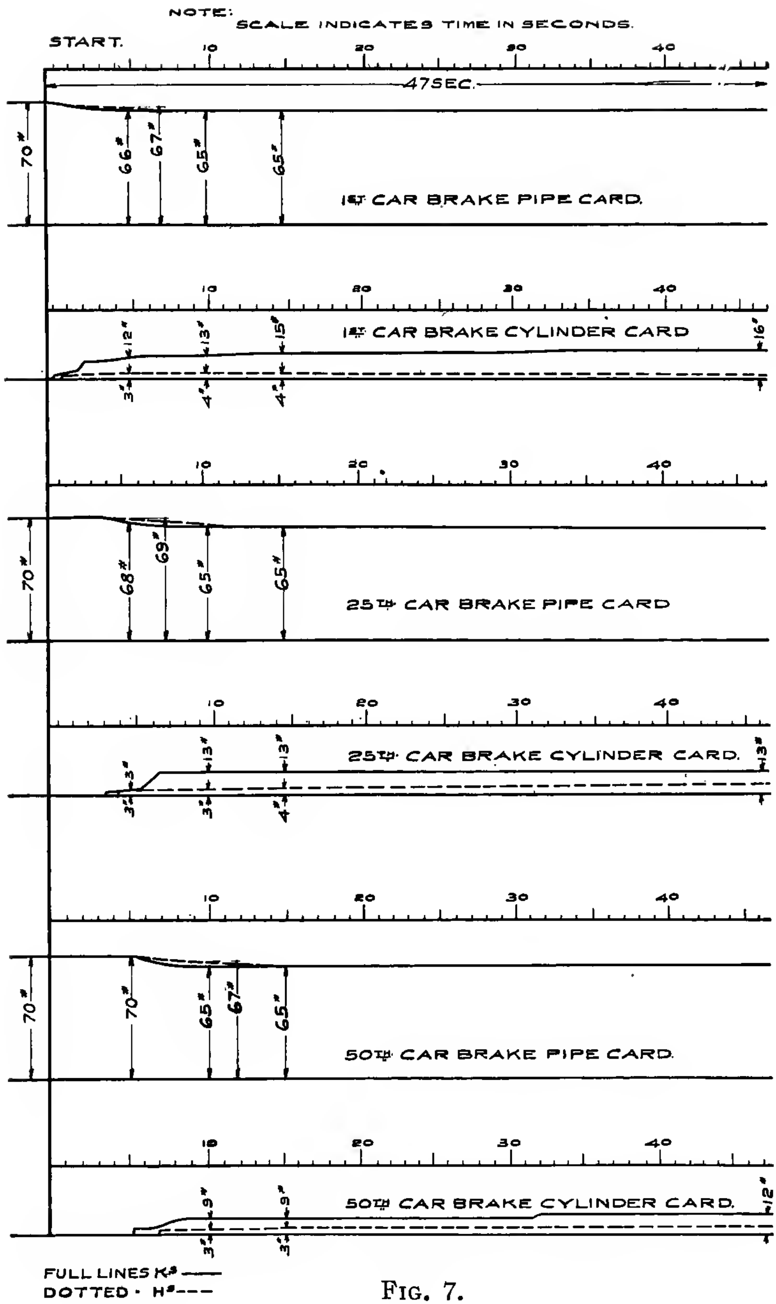
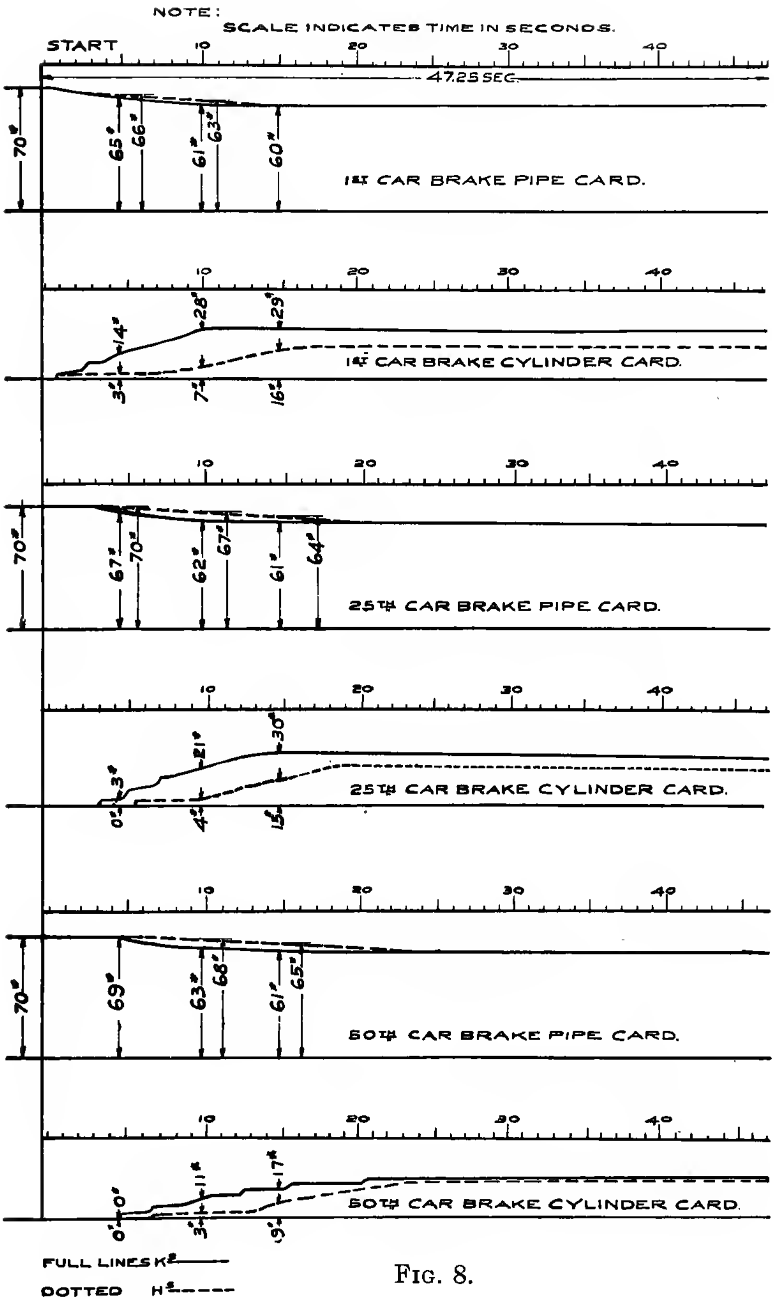

NOTE:
SCALE INDICATES TIME IN SECONDS.
START.
47 SEC.
1ST CAR BRAKE PIPE CARD.
1ST CAR BRAKE CYLINDER CARD
25TH CAR BRAKE PIPE CARD
25TH CAR BRAKE CYLINDER CARD.
50TH CAR BRAKE PIPE CARD.
50TH CAR BRAKE CYLINDER CARD.
FULL LINES K's
DOTTED - H's

Fig. 7.

Fig. 8 is similar to Fig. 7, except that a 10 pound reduction was made and consequently the differences in the results are more pronounced, both as between the brakes on the different cars and between the two types of valves with which the two trains were equipped.



NOTE:
SCALE INDICATES TIME IN SECONDS.
START
10
20
30
40
47.25 SEC.
70#
65#
66#
61#
63#
60#
1ST CAR BRAKE PIPE CARD.
14#
28#
29#
3#
7#
16#
1ST CAR BRAKE CYLINDER CARD.
70#
67#
70#
62#
67#
61#
64#
25TH CAR BRAKE PIPE CARD.
3#
21#
30#
0#
4#
15#
25TH CAR BRAKE CYLINDER CARD.
70#
69#
63#
68#
61#
65#
50TH CAR BRAKE PIPE CARD.
0#
0#
11#
17#
3#
9#
50TH CAR BRAKE CYLINDER CARD.
FULL LINES K2
DOTTED H2

FIG. 8.

Fig. 9 is similar to Fig. 8—the difference resulting from a 15 pound reduction having been made instead of 10 pounds.

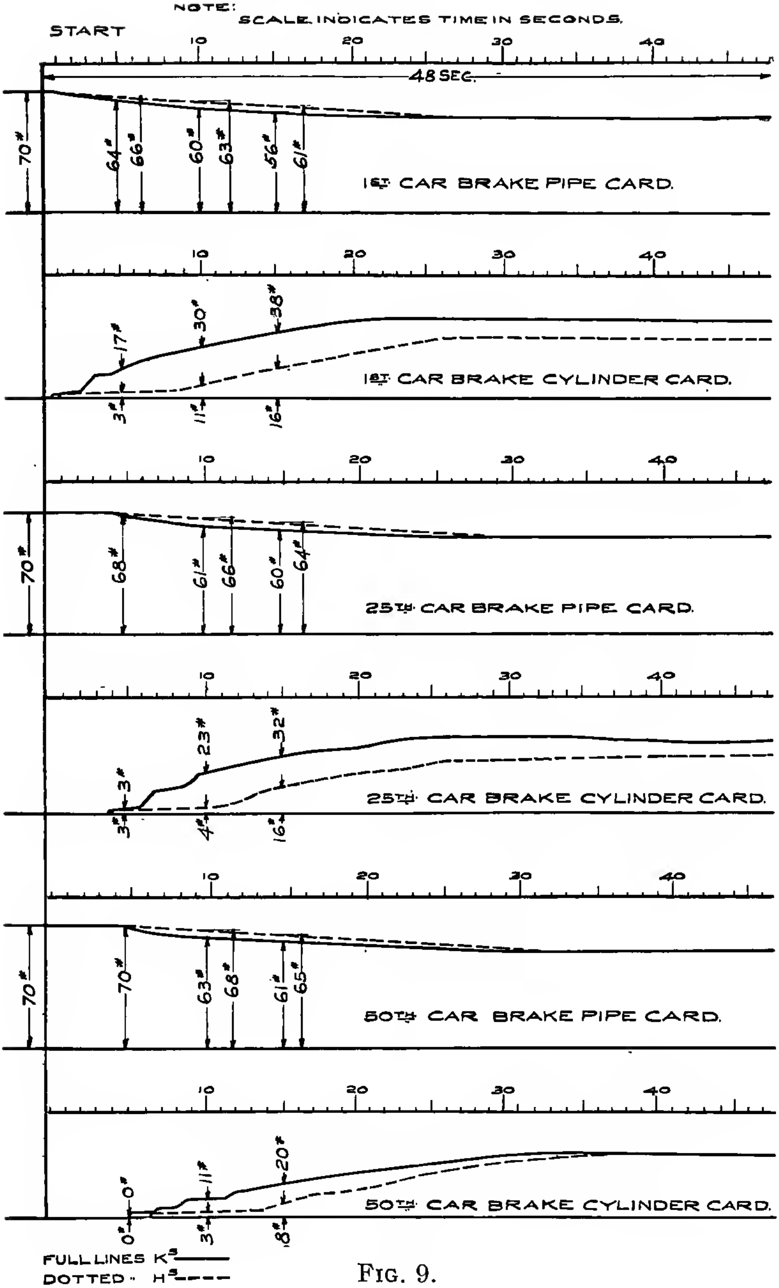

NOTE:
SCALE INDICATES TIME IN SECONDS.
START
10
20
30
40
48 SEC.
70#
64#
66#
60#
63#
56#
61#
1ST CAR BRAKE PIPE CARD.
17#
30#
38#
3#
11#
16#
1ST CAR BRAKE CYLINDER CARD.
68#
61#
66#
60#
64#
25TH CAR BRAKE PIPE CARD.
3#
23#
32#
4#
25TH CAR BRAKE CYLINDER CARD.
70#
63#
68#
61#
65#
50TH CAR BRAKE PIPE CARD.
0#
11#
20#
8#
50TH CAR BRAKE CYLINDER CARD.
FULL LINES K5
DOTTED " H5

Fig. 9.

Fig. 10 differs from the preceding figure because of a 20 pound reduction having been made instead of 15 pounds. This series makes quite clear how much more effective and controllable a brake becomes when the time required to obtain certain brake effectiveness from one end of the train to the other is reduced.

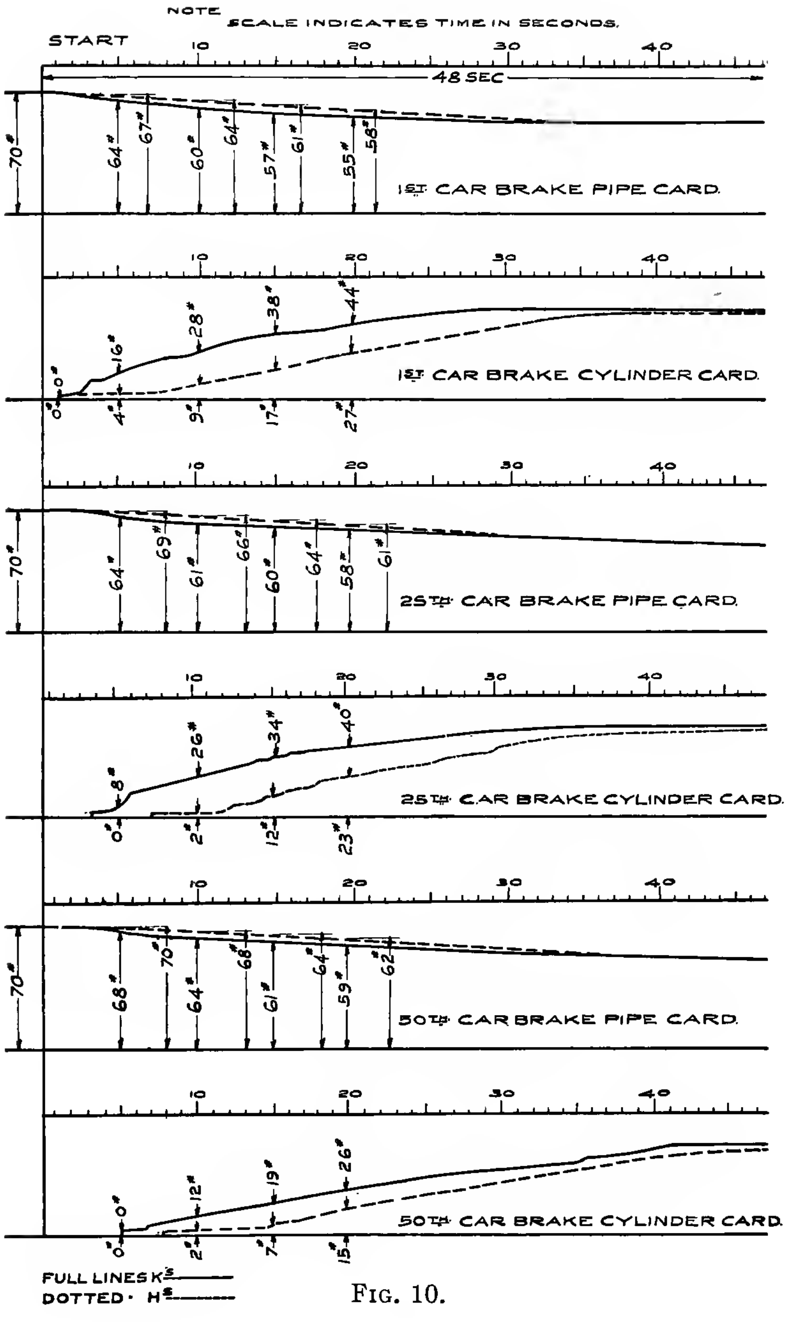
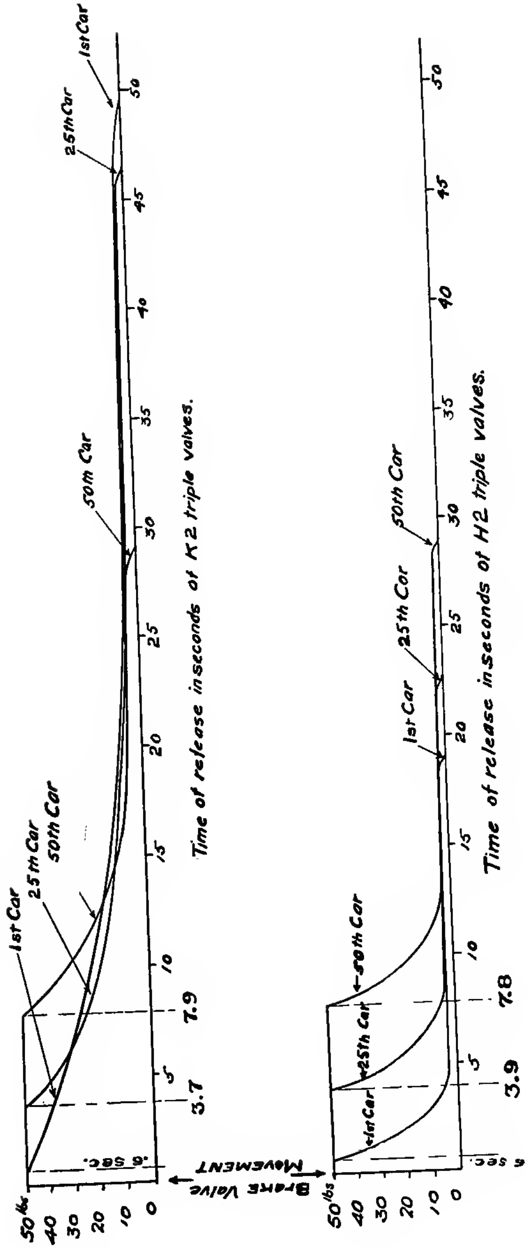

NOTE
SCALE INDICATES TIME IN SECONDS.
START
10
20
30
40
48 SEC
70#
64#
67#
60#
64#
57#
61#
55#
58#
1ST CAR BRAKE PIPE CARD.
0#
16#
28#
38#
44#
0#
4#
9#
17#
27#
1ST CAR BRAKE CYLINDER CARD.
64#
69#
61#
66#
60#
64#
58#
61#
25TH CAR BRAKE PIPE CARD.
8#
26#
34#
40#
0#
2#
12#
23#
25TH CAR BRAKE CYLINDER CARD.
68#
70#
64#
68#
61#
64#
59#
62#
50TH CAR BRAKE PIPE CARD.
0#
12#
19#
26#
0#
2#
7#
15#
50TH CAR BRAKE CYLINDER CARD.
FULL LINES K'S
DOTTED · H'S

FIG. 10.

Fig. 11 illustrates graphically both differences in time of release between the 1st, 25th and 50th cars of a train and the action of the brakes in the release when the retarded release type of triple valves is employed. It will be seen from the lower of the two sets of cylinder cards that the first brake was released in .6 of a second and was entirely off when the 25th brake commenced to release, which was about 3½ seconds later and that the 25th brake was off before the 50th commenced to release, which was about 4 seconds behind the 25th. It will thus be seen that there is an interval of about 9 seconds between the release of the 1st brake and the 50th and that the difference in the release of brakes between the 25th and 50th is 4 seconds—time enough for the retardation still going on at the rear to do considerable damage if the slack runs out.

From the upper set of cylinder cards, it will be seen that while the brakes commence to release with about the same difference in time that the release as a whole is very much more uniform—the effect being to eliminate surges in the train, due to brake release; thus doing away with a prolific source of damage and break-in-two.



Cylinder Cards Showing Release of K2 + H2 (H49) Triple Valves.
50 Car Train. — Brake Pipe Pressure 70 Lbs.
Main Reservoir Capacity 50000 Cu. In. — Main Reservoir Pressure 110 Lbs.

FIG. 11.

Fig. 12 illustrates the difference in time of release between the 1st, 25th and 50th cars of a train, both as regards the different cars and two different types of valves. This and the cards shown on the following three figures are instructive also as illustrating the rate of rise of brake pipe pressure of a train of this length, namely, 50 cars.

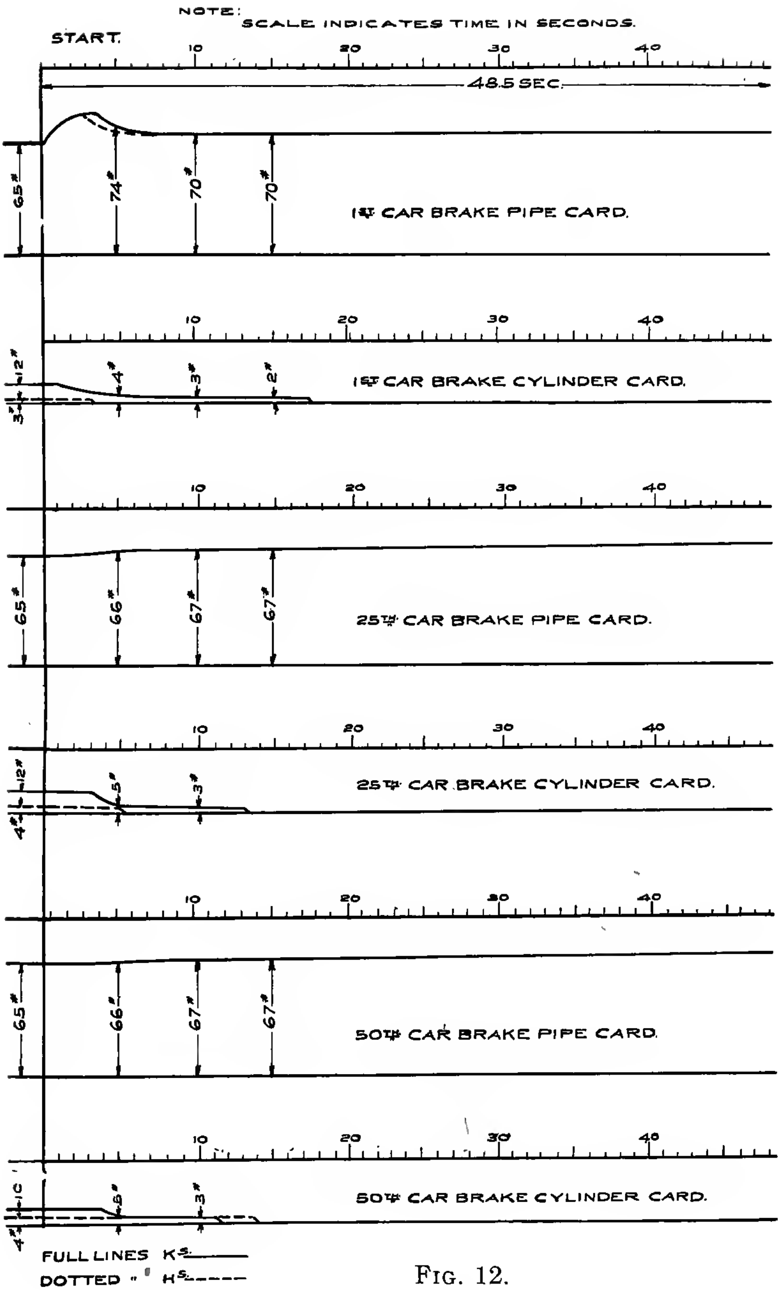

NOTE:
SCALE INDICATES TIME IN SECONDS.
START.
48.5 SEC.
65#
74#
70#
70#
1ST CAR BRAKE PIPE CARD.
12#
3#
4#
3#
2#
1ST CAR BRAKE CYLINDER CARD.
65#
66#
67#
67#
25TH CAR BRAKE PIPE CARD.
12#
4#
5#
3#
25TH CAR BRAKE CYLINDER CARD.
65#
66#
67#
67#
50TH CAR BRAKE PIPE CARD.
10
4#
6#
3#
50TH CAR BRAKE CYLINDER CARD.
FULL LINES K.S.
DOTTED " H.S.

FIG. 12.

Fig. 13 differs from Fig. 12 in that it is a release after a 10-pound reduction instead of a 5-pound.

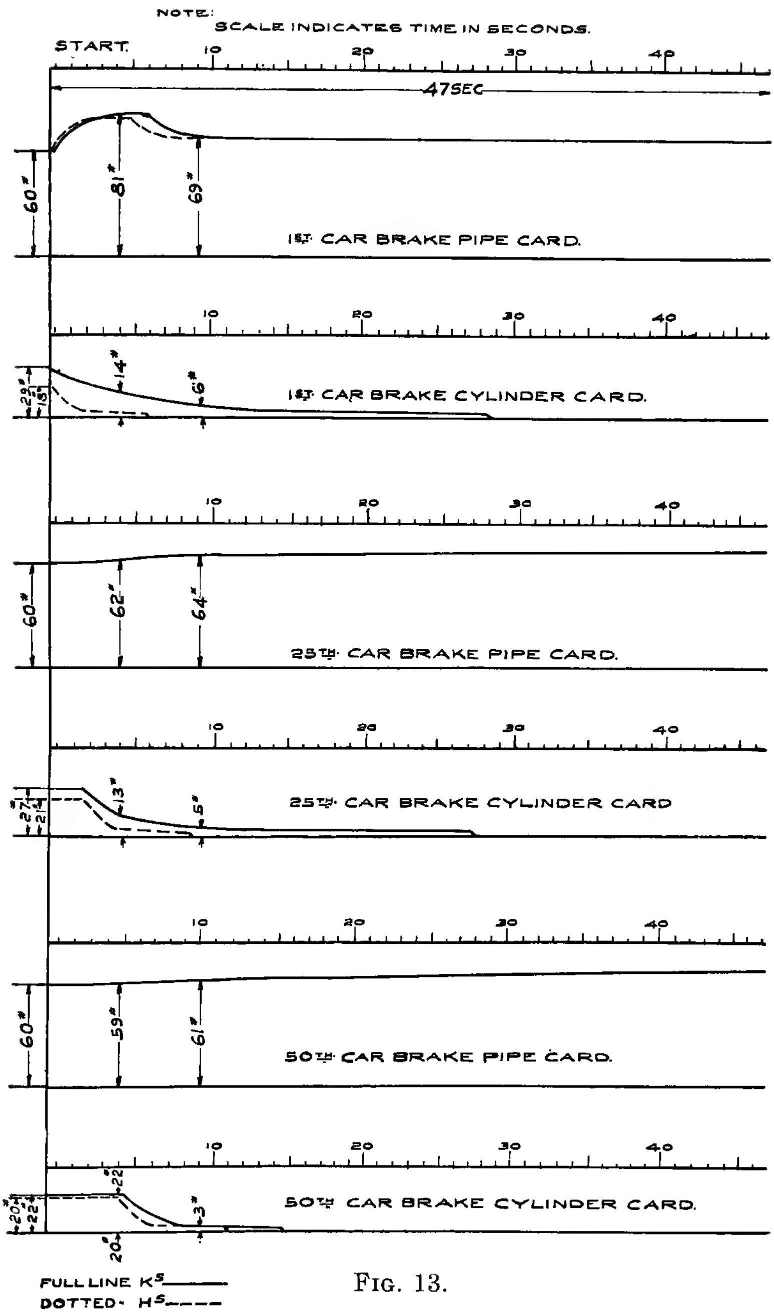

NOTE:
SCALE INDICATES TIME IN SECONDS.
START
10
20
30
40
47 SEC
60#
81#
69#
1ST CAR BRAKE PIPE CARD.
14#
6#
29#
15#
1ST CAR BRAKE CYLINDER CARD.
60#
62#
64#
25TH CAR BRAKE PIPE CARD.
13#
5#
27#
21#
25TH CAR BRAKE CYLINDER CARD
60#
59#
61#
50TH CAR BRAKE PIPE CARD.
22#
3#
20#
22#
20#
50TH CAR BRAKE CYLINDER CARD.
FULL LINE K5
DOTTED H5

FIG. 13.

Fig. 14 illustrates the difference in time of commencement of release of the brake and fall of cylinder pressure on the cars after a 15-pound reduction.

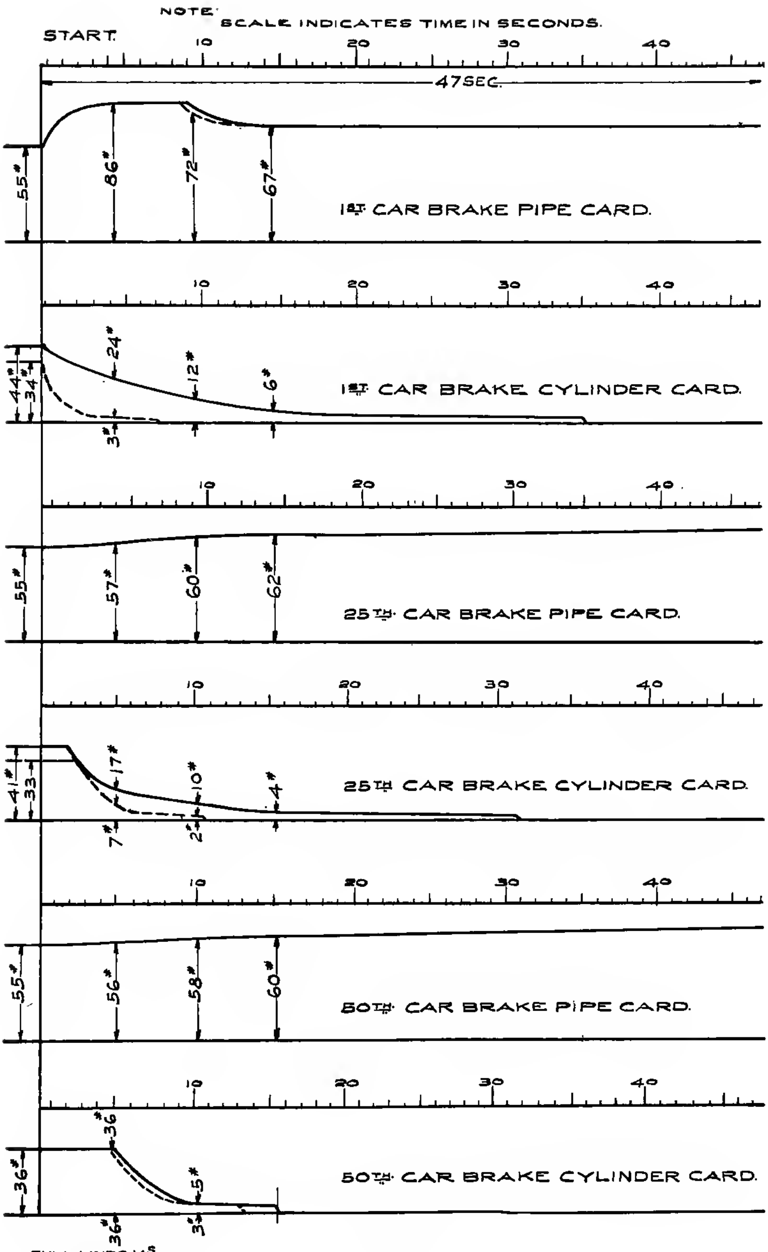

NOTE
SCALE INDICATES TIME IN SECONDS.
START
10
20
30
40
47 SEC.
55#
86#
72#
67#
1ST CAR BRAKE PIPE CARD.
44#
34#
24#
12#
6#
3#
1ST CAR BRAKE CYLINDER CARD.
55#
57#
60#
62#
25TH CAR BRAKE PIPE CARD.
41#
33
17#
10#
4#
7#
2#
25TH CAR BRAKE CYLINDER CARD.
55#
56#
58#
60#
50TH CAR BRAKE PIPE CARD.
36#
36#
5#
36#
3#
50TH CAR BRAKE CYLINDER CARD.
FULL LINES K's
DOTTED " H's

FIG. 14.

Fig. 15. The cards of this figure are taken from a 20 pound reduction and illustrate the rate of rise of brake pipe pressure between the different cars of the train, the amount of cylinder pressure obtained, the time of release between the different cars, and the difference in the rate of release of cylinder pressure between the different cars of the train and between the different types of valves. For example, with the old type of valve, the pressure was all out of the cylinder of the first car 3 seconds before the brake of the last car commenced to release; while with the new type of valve, there was 25 pounds in the cylinder of the first car when the brake of the last or 50th car commenced to release and about 10 pounds in the cylinder of the first car when the effective pressure was out of the cylinder of the last car. In other words, the brake of the last car was released before that of the first car; thus the difference in time due to length of train was practically eliminated. The great value of this can only be appreciated by those who know the effects of having the rear end of the train anchored while the front end is running free.

Whatever difference in cylinder pressure there appears on the different sets of charts above mentioned has been due to the influence of the time factor as the piston travel was uniform. In the figures that follow the difference in cylinder pressure that appears is due to variation of piston travel, that is, increase or decrease of brake piston movement, which by the grace of somebody may exist before the shoes bear on the wheels.

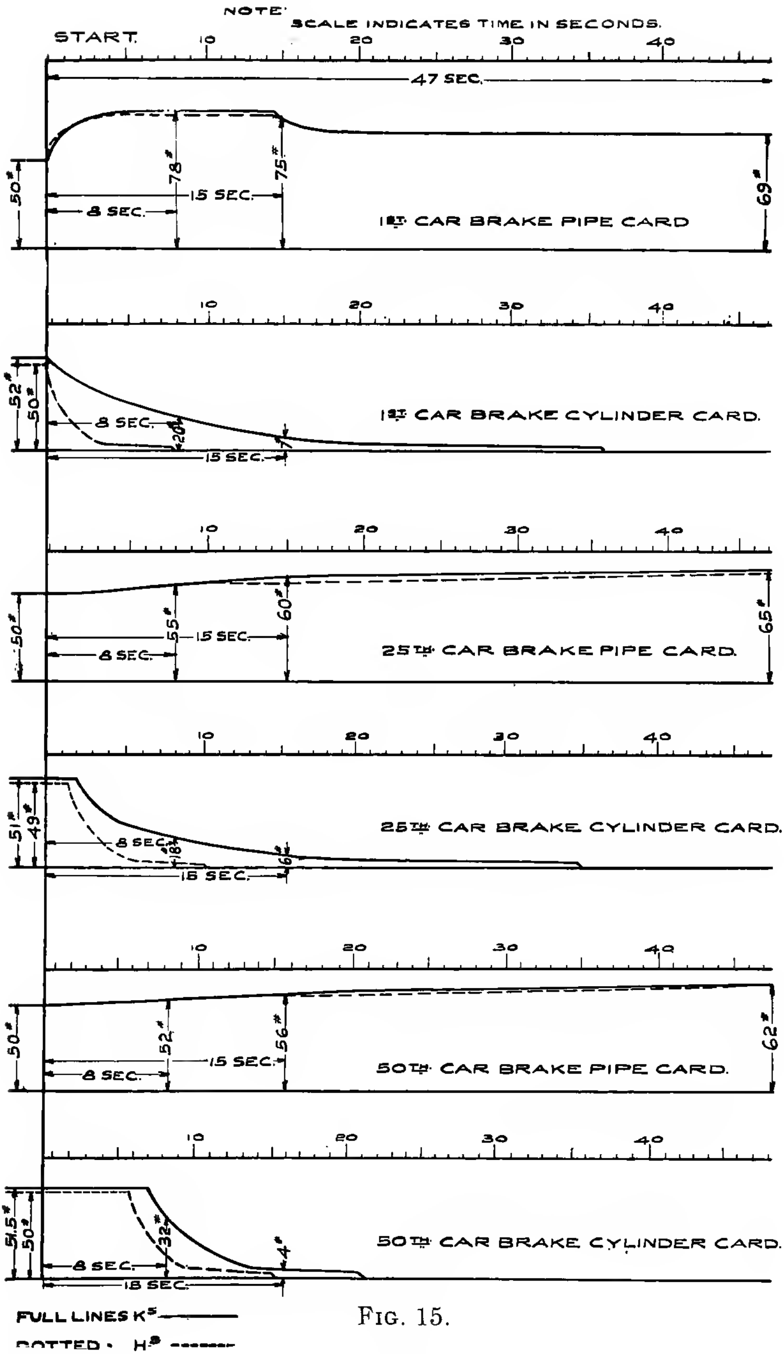

NOTE: SCALE INDICATES TIME IN SECONDS.
START
10
20
30
40
47 SEC.
50#
78#
75#
69#
15 SEC.
8 SEC.
1ST CAR BRAKE PIPE CARD
52#
50#
8 SEC.
20#
7#
15 SEC.
1ST CAR BRAKE CYLINDER CARD.
50#
55#
60#
65#
15 SEC.
8 SEC.
25TH CAR BRAKE PIPE CARD.
51#
49#
8 SEC.
18#
6#
15 SEC.
25TH CAR BRAKE CYLINDER CARD.
50#
52#
56#
62#
15 SEC.
8 SEC.
50TH CAR BRAKE PIPE CARD.
51.5#
50#
32#
4#
8 SEC.
18 SEC.
50TH CAR BRAKE CYLINDER CARD.
FULL LINES K5
DOTTED H3

FIG. 15.

Fig. 16. The significance of the curves of this chart is pointed out on page 19 of this reprint of the paper. A prolonged study of this chart will cause considerable reflection, if nothing more concrete, and perhaps some may even ask these questions—how did we ever permit such conditions to come into existence, and why do we permit them to continue?

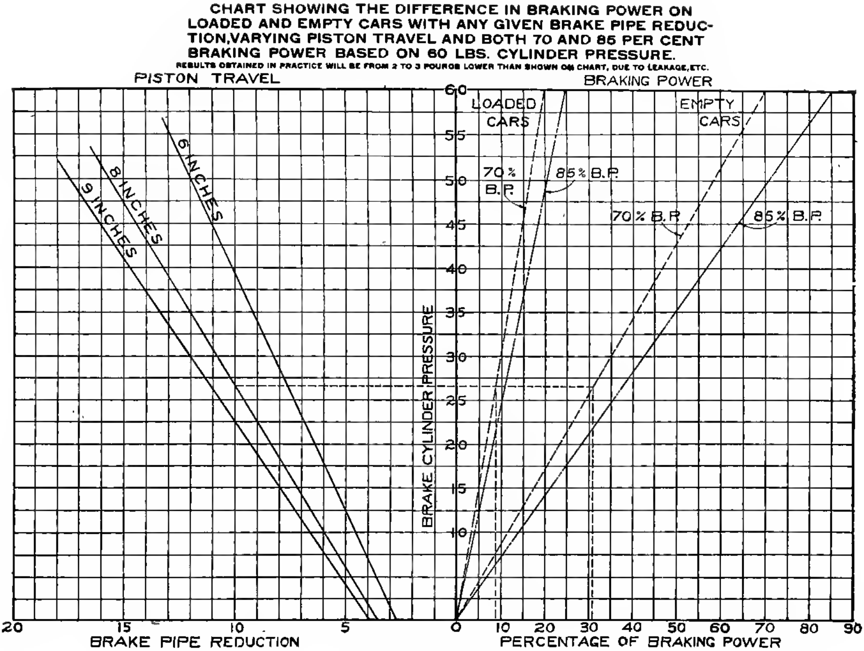
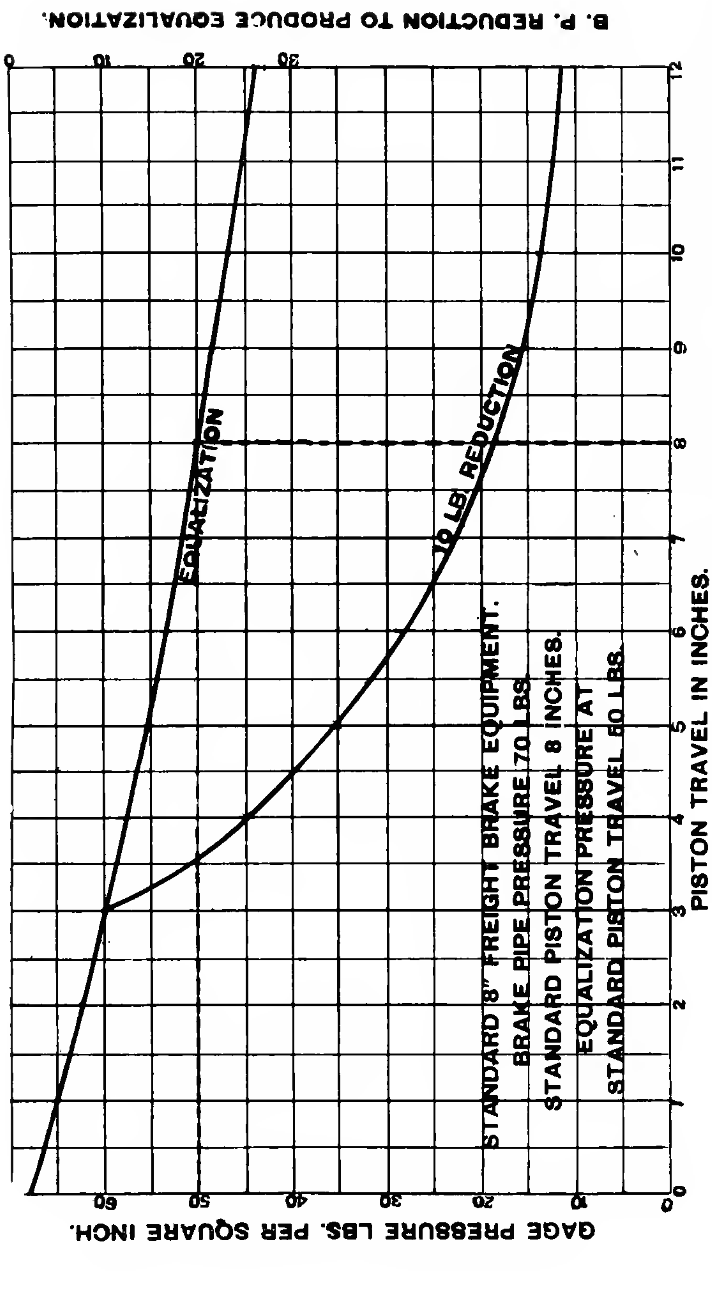


CHART SHOWING THE DIFFERENCE IN BRAKING POWER ON LOADED AND EMPTY CARS WITH ANY GIVEN BRAKE PIPE REDUCTION, VARYING PISTON TRAVEL AND BOTH 70 AND 85 PER CENT BRAKING POWER BASED ON 60 LBS. CYLINDER PRESSURE.
RESULTS OBTAINED IN PRACTICE WILL BE FROM 2 TO 3 POUNDS LOWER THAN SHOWN ON CHART, DUE TO LEAKAGE, ETC.
PISTON TRAVEL
BRAKING POWER
6 INCHES
8 INCHES
9 INCHES
LOADED CARS
EMPTY CARS
70% B.P.
85% B.P.
70% B.P.
85% B.P.
BRAKE CYLINDER PRESSURE
60
55
50
45
40
35
30
25
20
15
10
20 15 10 5 0
BRAKE PIPE REDUCTION
10 20 30 40 50 60 70 80 90
PERCENTAGE OF BRAKING POWER
SERVICE EQUALIZATION 53.9 POUNDS

FIG. 16.

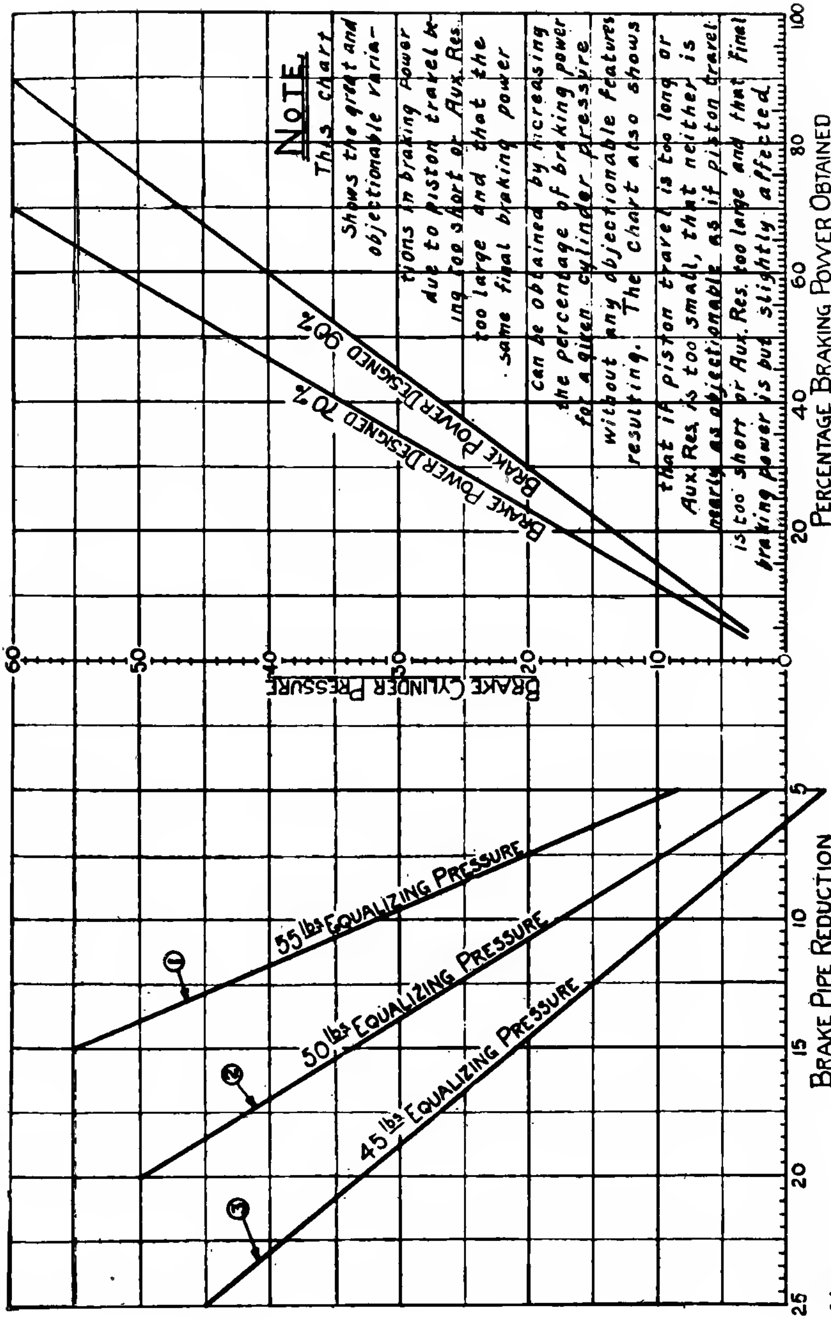
Fig. 17. This chart is very instructive as illustrating how the braking power may vary, due to no other cause than lack of piston travel maintenance. As the chart is largely self-explanatory, it will be sufficient to point out that the air stored in the auxiliary reservoir at 70 pounds may equalize into the brake cylinder at any pressure from 67 pounds down to 44 pounds contingent only upon difference in piston travel. But as the damage is done long before equalization of pressure is reached, we would show what results from a 10-pound reduction, which is the critical one of an application. Here we see the pressure obtained from a 10-pound reduction may vary from 60 pounds with 3″ piston travel to only 12 pounds with 12″ piston travel, and what is worse in its effect in producing shocks that 60 pounds is obtained in the same time as the 12 pounds. Of course, there may be any of the variations between these two extremes. Now what does the engineer have to do with this, or how is he to prevent the results? Every car man and inspector should be drilled until he knows by heart what produces these curves and what their effects may be.



EFFECT OF PISTON TRAVEL ON BRAKE.
CYLINDER PRESSURE OBTAINED FOR 10 LB.
REDUCTION AND ON EQUALIZATION.

FIG. 17.

Fig. 18. This chart carries the investigation of the effect of varying piston travel further, in that we are able to see what it means in the braking power on the car and from this infer what such un-uniformity may mean to the train as a whole, particularly if we figure the various combinations and distribution that may occur. It will be seen that with the braking power designed for 70% of the light weight of the car a 10-pound reduction will result in about 9 pounds cylinder pressure and about 10% braking powei on the car with long piston travel; while on the car with short piston travel for the same direction and in the same time the cylinder pressure will be 32 pounds and the braking power 35%. A further investigation of the curves will disclose a multitude of possible variations which, fortunately, may be held down to very narrow extremes by very little care, which, however, must be given before the train leaves the terminal, as the engineer is not furnished with any mechanism that will compensate for improper conditions of brake equipment, nor can he expect except in rare instances to avoid the consequences



NOTE-
BRAKING POWER BASED ON 60 lbs. BRAKE CYLINDER PRESSURE
① INDICATES TOO SHORT PISTON TRAVEL OR TOO LARGE AUXILIARY RESERVOIR.
② " CORRECT " AND PROPER "
③ " TOO LONG " OR TOO SMALL "

FIG. 18.

Fig. 19 is a different method of illustrating this matter, but more graphically develops the comparatively slight differences in the equalized pressures and the great differences for partial applications for the same difference in piston travel. Also that the very high cylinder pressure resulting from short piston travel is obtained with less than half the reduction and in less than half the time that the equalized and lower pressure is obtained with the long travel. Plainly, few know that these things exist or few care—either horn of the dilemma is not comfortable and I may say neither is profitable. *Fortunately the most extreme neglect will not destroy the brake as an emergency safety device, but considerable care is required to retain its efficiency as a service brake, and this is all the more important as serious losses may otherwise result.* In other words, as with any thing less mechanical, certain physical conditions must exist if we are to obtain profitable and desired instead of unprofitable and undesired results. It would not be necessary to mention this if we were speaking of anything else but the air brake.

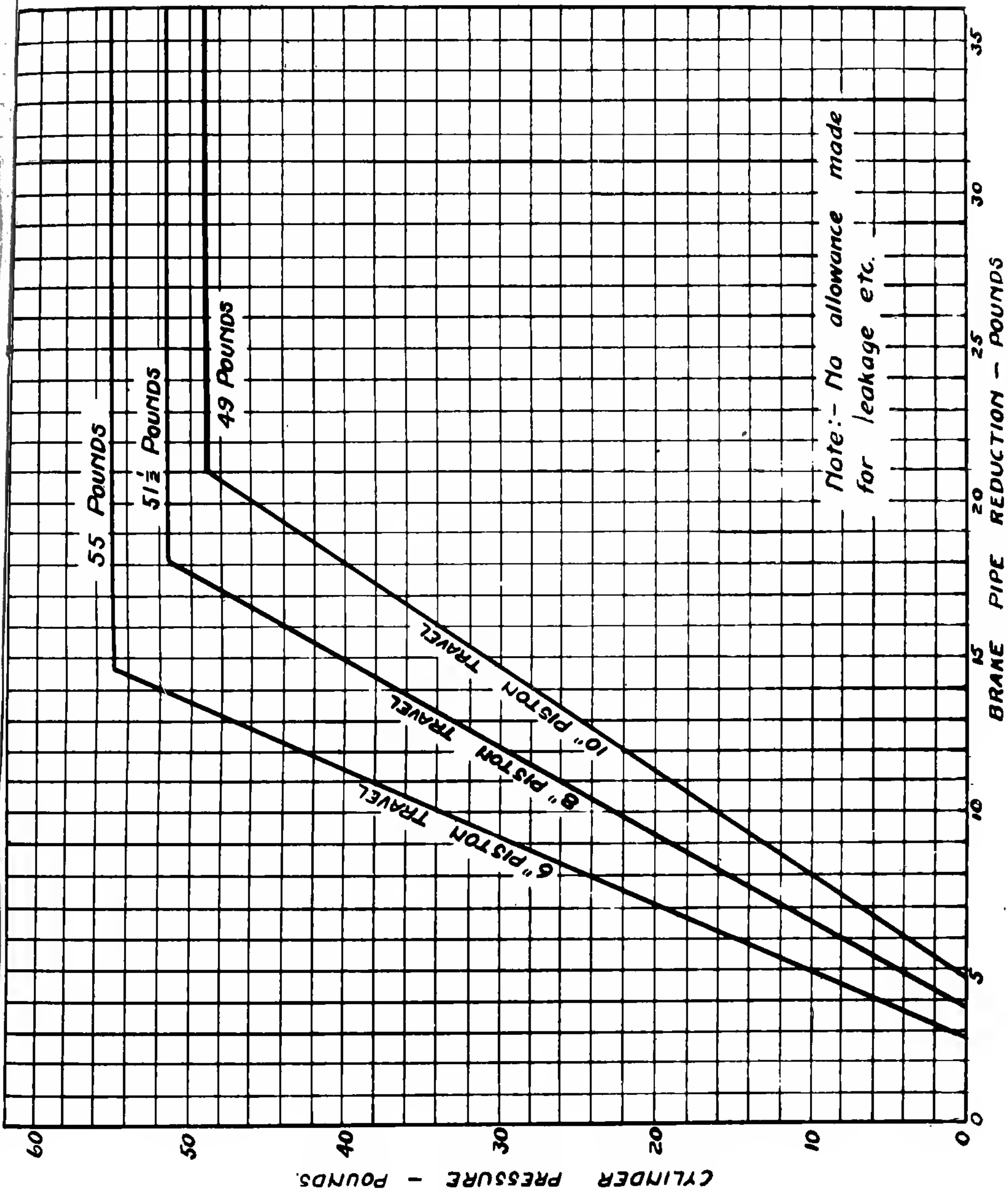

55 POUNDS
51½ POUNDS
49 POUNDS
10" PISTON TRAVEL
8" PISTON TRAVEL
6" PISTON TRAVEL
Note:- No allowance made for leakage etc.
0
5
10
15
20
25
30
35
BRAKE PIPE REDUCTION - POUNDS
0
10
20
30
40
50
60
CYLINDER PRESSURE - POUNDS.

FIG 19

Fig. 20 still further illustrates piston travel effects, it being hoped by the number and graphicness of the illustrations that some sort of notice will be taken of the importance of this element in its effect on train control. In this chart, the variation of both pressure and difference in percentage of braking power that may occur, either side of that desired in the design is shown.

Figs. 19 and 20 are analyzed on page 10 of the paper to some extent, to which the reader is referred. It is hoped that something has been said on this part of the subject which will impress upon all concerned the necessity of giving it the consideration that results in some action being taken.

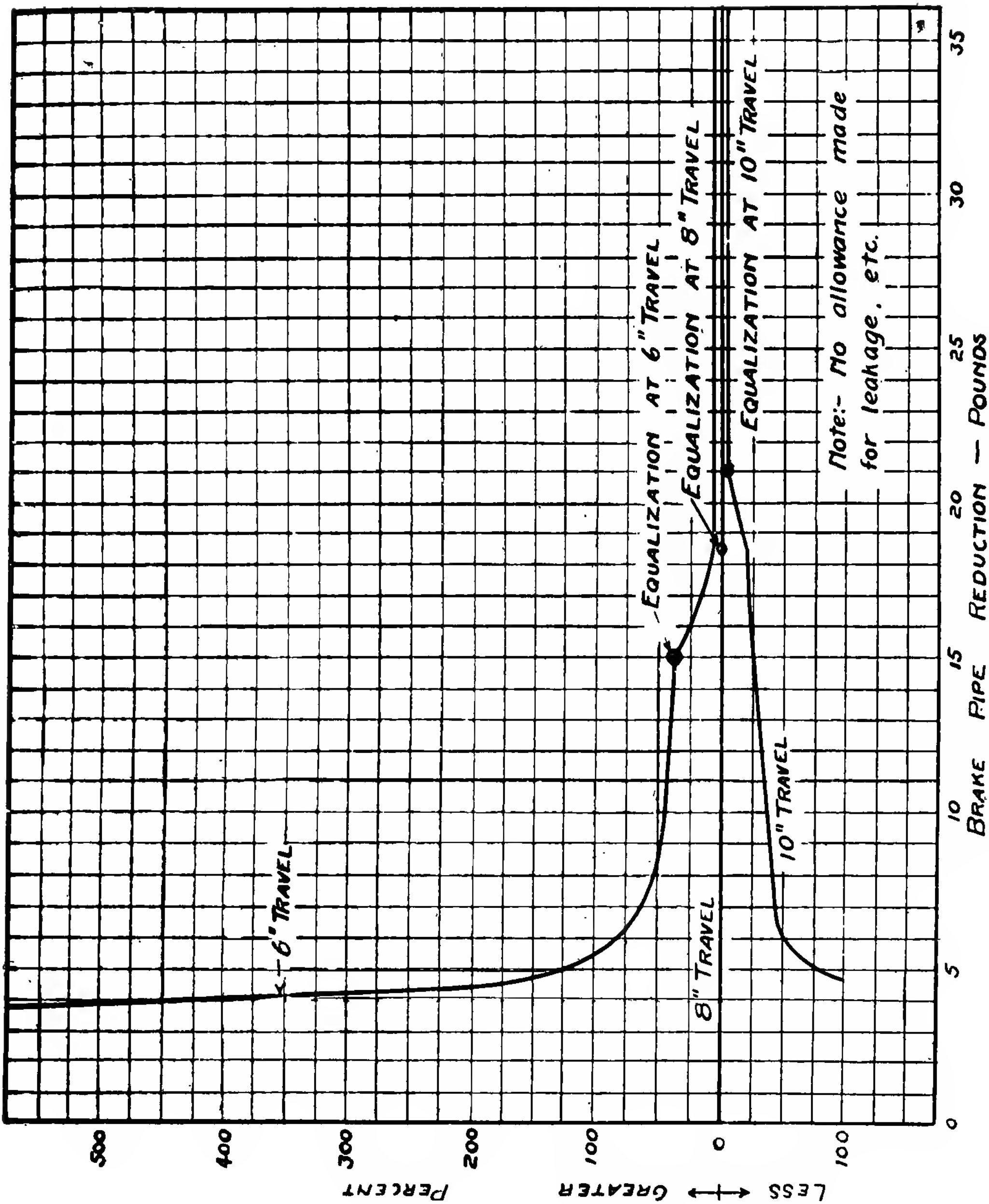
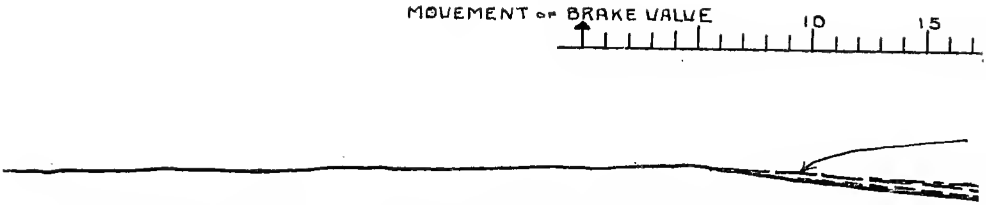

EQUALIZATION AT 6" TRAVEL
EQUALIZATION AT 8" TRAVEL
EQUALIZATION AT 10" TRAVEL
Note:- No allowance made for leakage, etc.
6" TRAVEL
8" TRAVEL
10" TRAVEL
0 5 10 15 20 25 30 35
BRAKE PIPE REDUCTION — POUNDS
500 400 300 200 100 0 100
PERCENT
GREATER ↔ LESS

Fig. 21. This chart illustrates graphically the movement of the air and the action of the brakes both when the brake valve is manipulated, in releasing the brakes of a 75-car train, as it should be and as it should *not* be. Curve 1 proves how serious the improper manner of releasing the brakes may be—the result being "stuck brakes" and undesired quick action on the next application. The curves of this and the following figure are interesting and instructive in showing how the pressure rises and falls in different parts of the train and that the time interval between the action of the brake first and last is a factor to be reckoned with.

From a train operating standpoint, the curves shown on this chart are perhaps the most important ever recorded, for an inspection of those curves showing improper operation will demonstrate that a great many troubles and losses with the brake are due entirely to the improper use of the full release position. One reason for calling attention to these particularly is that all the evils resultant from such manipulation can be avoided without the expenditure of a dollar for apparatus or repairs. It will be seen from curves 1 and 3 that overcharging, stuck brakes, undesired quick action are the resultant of such improper methods of manipulation. It almost seems needless to say that in a train with this we have flat wheels, cracked wheels, broken wheels, buckling of trains, and break-in-twos, as well as a great number of happenings of lesser significance.

Another thing, however, should be pointed out, namely, that such methods in grade work result in the forward brakes of the train doing practically all the work of controlling the train, which viewed from any standpoint is bad.

Curves 2 and 4. (Fig. 21.) It will be seen that none of these things result when the proper method is employed. In fact, just the contrary for the operation of the brakes is then all that can be desired as far as brake valve control is concerned. A note on each curve briefly gives the operation and result, but an individual analysis of each of the curves cannot fail to convince all concerned that there are some things to avoid when operating the brakes.



50 CAR TRAIN. 15 LB. BRAKE PIPE REDUCTION --- ALL APPLIED. BRAKE VALVE HANDLE PLACED IN FULL RELEASE F FOR 30 SECONDS: BRAKE VALVE HANDLE WAS THEN PLACED NING POSITION FOR 15 SECONDS. BRAKES FROM 1 TO 14, IN AND 17 RE-APPLIED DUE TO OVERCHARGING, AND REMAINED FOLLOWED BY A 10 LB. BRAKE PIPE REDUCTION, ALL BRAKES BUT WITH 52 LBS. ON HEAD END AND ONLY 5 LBS. ON REAR.

50 CAR TRAIN. 15 LB. BRAKE PIPE REDUCTION --- ALI APPLIED. BRAKE VALVE HANDLE PLACED IN FULL RELEASE FOR 10 SECONDS: BRAKE VALVE HANDLE WAS THEN PLACE NING POSITION FOR 35 SECONDS. BRAKES 1 AND 2 RE-APP TO OVERCHARGING FOLLOWED BY A 10 LB. BRAKE PIPE RE ALL BRAKES APPLIED, AND WITH PROPER UNIFORMITY.

Figs. 22 to 27, inclusive are intended to show the difference in time in the release of the brakes when using running position with a 30-car train and full release position with an 80-car train after both a 10 and 20-pound reduction. These curves also show that the rise of pressure is much more rapid with the brake valve in running position for a 30-car train than in full release position for an 80-car train. In fact, these charts were made to demonstrate, to some who doubted, that the brake which will release when full release position is used on an 80-car train is even more certain to release in a 30-car train if only running position is used.

Another point worthy of notice is that some of the brakes on the 80-car train had not released by the time the brake valve handle was returning to running position, consequently, they were released from running position. The vertical lines show when the triple valve went to release position, as at this point the indicator was closed and opened again quickly. Some of the lessons to be learned from these four charts are, if the brake valve handle is held in release position long enough to insure that all brakes are released while the handle is in this position, that the head end of the train will be overcharged, that the time of the release of the brake depends more upon the length of the train than the position of the brake valve handle and that the rise of brake pipe pressure when releasing the brakes, like the fall of pressure when applying the brakes, is also dependent more upon the length of the train than upon the position of the brake valve, and finally that the interval between the release of the first brake and the last is dependent upon the length of train. Of course, these differences both in application and release are very much reduced and greater uniformity secured by the later type of triple valve, but even with these, better results will be obtained if it is understood that different conditions involve different results unless the manipulation be modified accordingly.

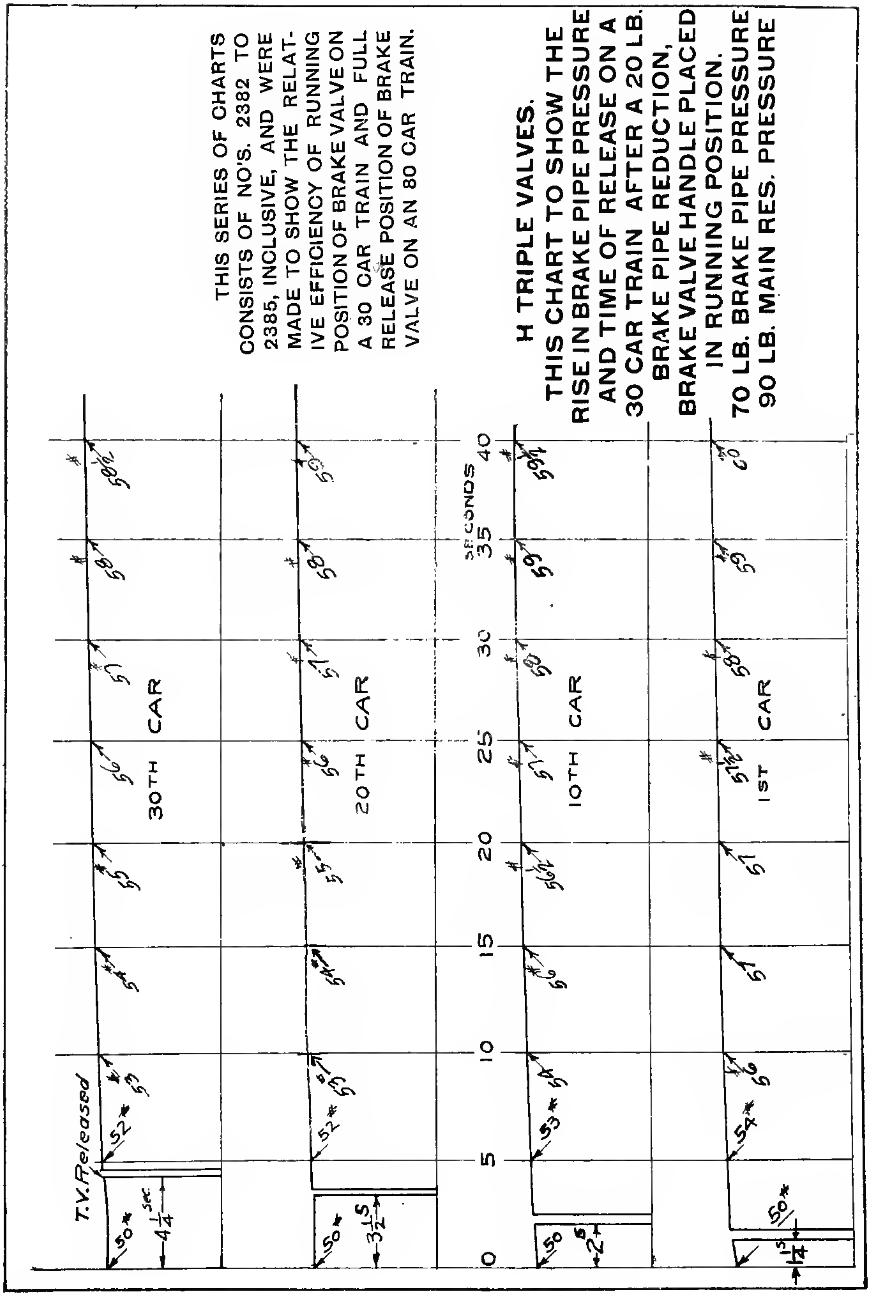

THIS SERIES OF CHARTS
CONSISTS OF NO'S. 2382 TO
2385, INCLUSIVE, AND WERE
MADE TO SHOW THE RELAT-
IVE EFFICIENCY OF RUNNING
POSITION OF BRAKE VALVE ON
A 30 CAR TRAIN AND FULL
RELEASE POSITION OF BRAKE
VALVE ON AN 80 CAR TRAIN.
H TRIPLE VALVES.
THIS CHART TO SHOW THE
RISE IN BRAKE PIPE PRESSURE
AND TIME OF RELEASE ON A
30 CAR TRAIN AFTER A 20 LB.
BRAKE PIPE REDUCTION,
BRAKE VALVE HANDLE PLACED
IN RUNNING POSITION.
70 LB. BRAKE PIPE PRESSURE
90 LB. MAIN RES. PRESSURE
30TH CAR
20TH CAR
10TH CAR
1ST CAR
T.V. Released
SECONDS
0
5
10
15
20
25
30
35
40

FIG. 22.

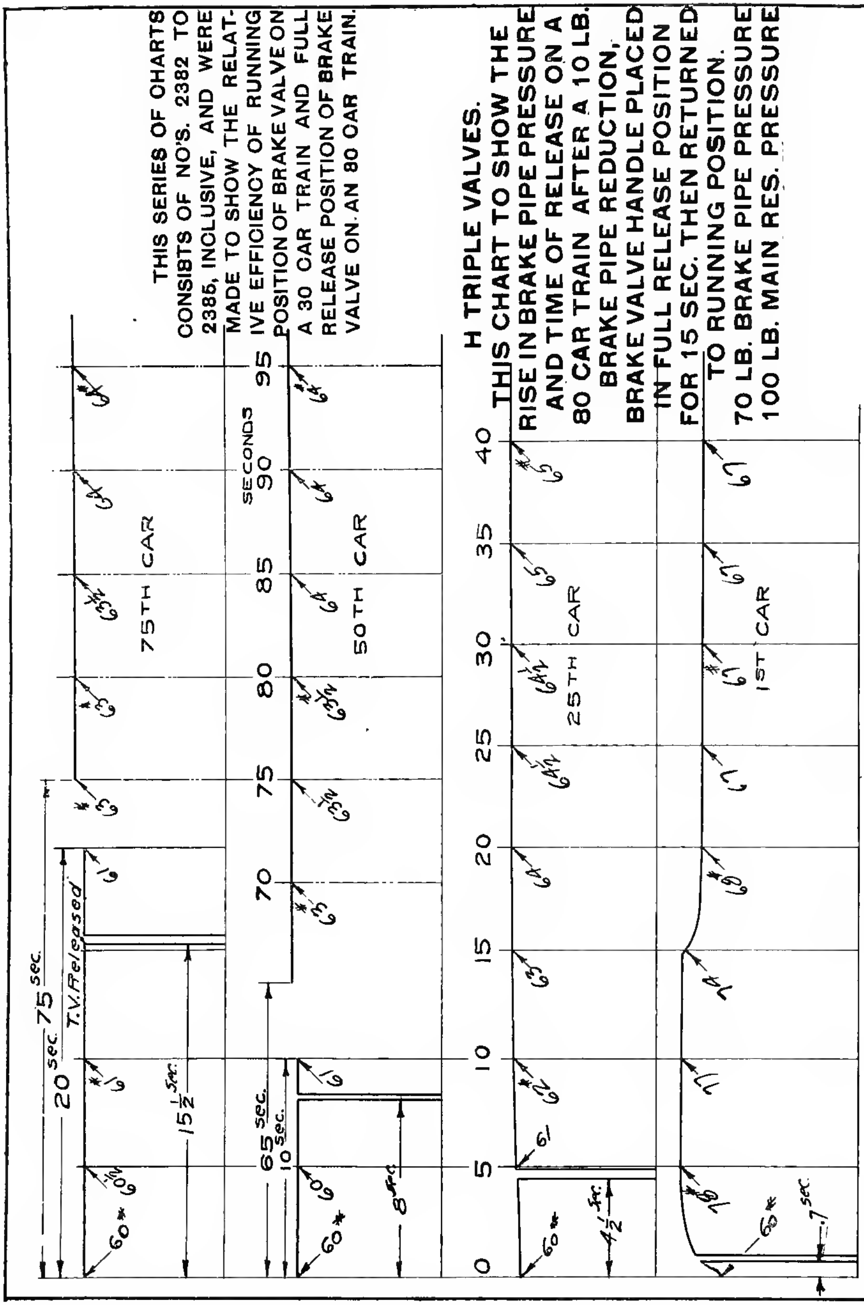

THIS SERIES OF CHARTS CONSIBTS OF NO'S. 2382 TO 2385, INCLUSIVE, AND WERE MADE TO SHOW THE RELATIVE EFFICIENCY OF RUNNING POSITION OF BRAKE VALVE ON A 30 CAR TRAIN AND FULL RELEASE POSITION OF BRAKE VALVE ON AN 80 CAR TRAIN.
H TRIPLE VALVES.
THIS CHART TO SHOW THE RISE IN BRAKE PIPE PRESSURE AND TIME OF RELEASE ON A 80 CAR TRAIN AFTER A 10 LB. BRAKE PIPE REDUCTION, BRAKE VALVE HANDLE PLACED IN FULL RELEASE POSITION FOR 15 SEC. THEN RETURNED TO RUNNING POSITION.
70 LB. BRAKE PIPE PRESSURE
100 LB. MAIN RES. PRESSURE
75TH CAR
50TH CAR
25TH CAR
1ST CAR
SECONDS
T.V. Released

FIG. 23.

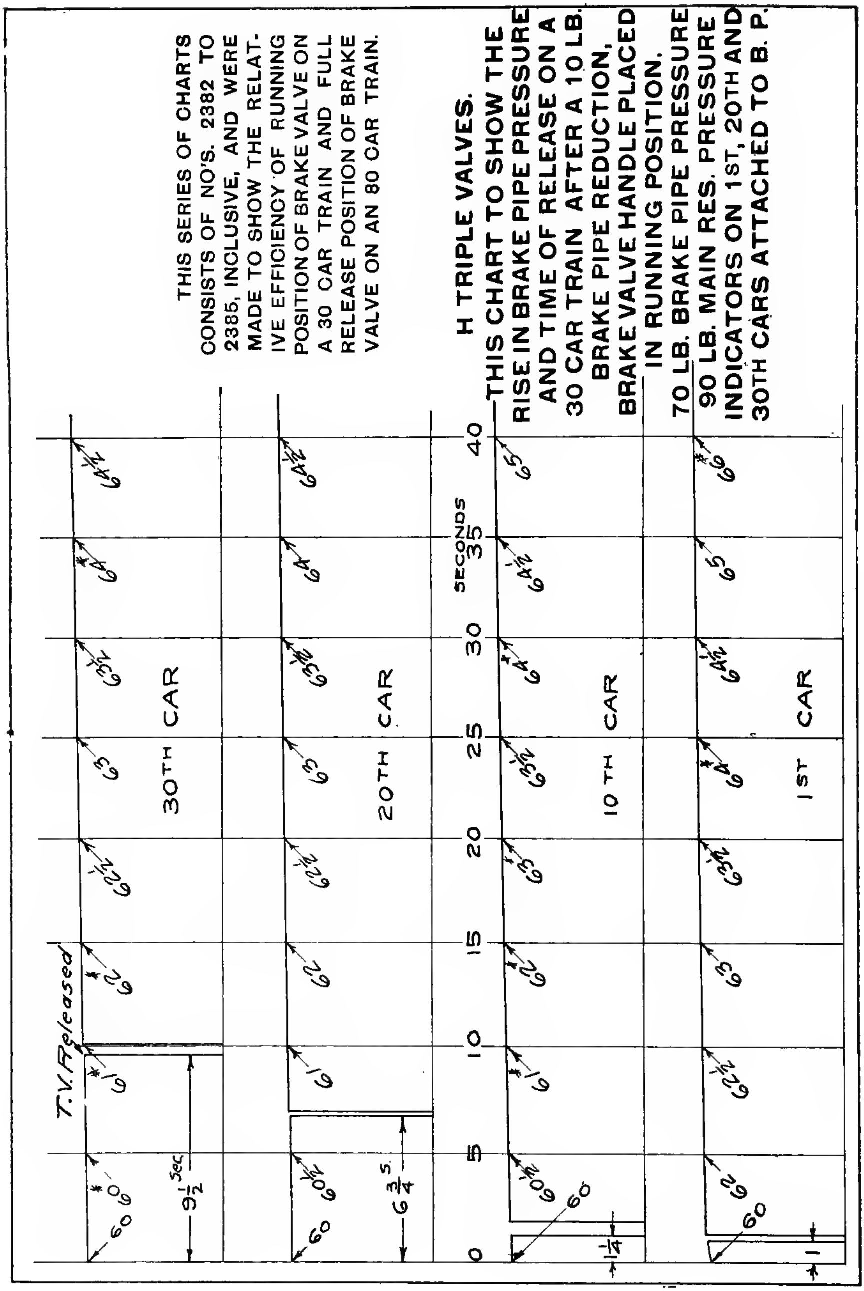

THIS SERIES OF CHARTS CONSISTS OF NO'S. 2382 TO 2385, INCLUSIVE, AND WERE MADE TO SHOW THE RELATIVE EFFICIENCY OF RUNNING POSITION OF BRAKE VALVE ON A 30 CAR TRAIN AND FULL RELEASE POSITION OF BRAKE VALVE ON AN 80 CAR TRAIN.
H TRIPLE VALVES.
THIS CHART TO SHOW THE RISE IN BRAKE PIPE PRESSURE AND TIME OF RELEASE ON A 30 CAR TRAIN AFTER A 10 LB. BRAKE PIPE REDUCTION, BRAKE VALVE HANDLE PLACED IN RUNNING POSITION.
70 LB. BRAKE PIPE PRESSURE
90 LB. MAIN RES. PRESSURE
INDICATORS ON 1ST, 20TH AND 30TH CARS ATTACHED TO B. P.
T.V. Released
30TH CAR
20TH CAR
10TH CAR
1ST CAR
SECONDS
0
5
10
15
20
25
30
35
40

FIG. 24.

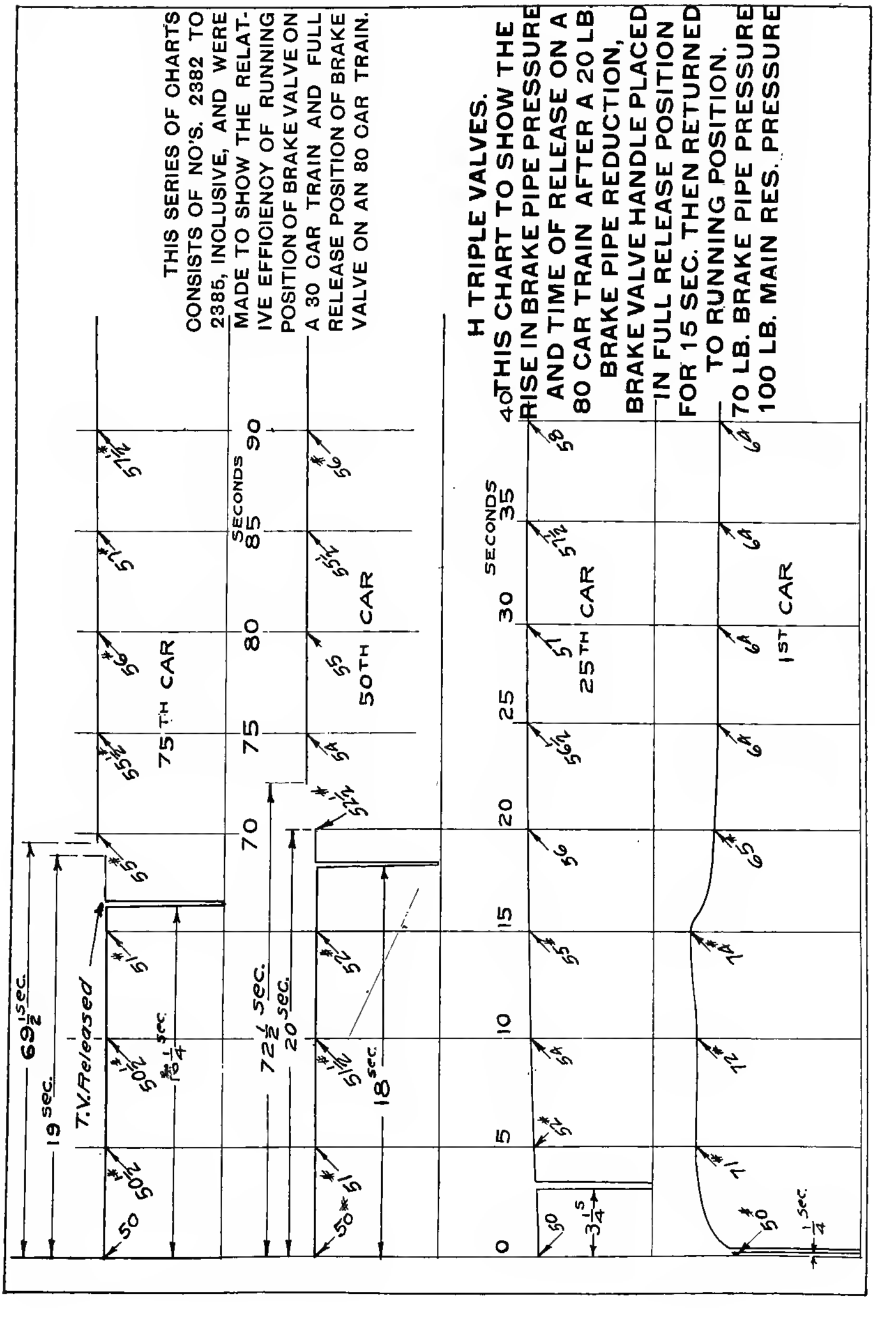

THIS SERIES OF CHARTS CONSISTS OF NO'S. 2382 TO 2385, INCLUSIVE, AND WERE MADE TO SHOW THE RELATIVE EFFICIENCY OF RUNNING POSITION OF BRAKE VALVE ON A 30 CAR TRAIN AND FULL RELEASE POSITION OF BRAKE VALVE ON AN 80 CAR TRAIN.
H TRIPLE VALVES.
THIS CHART TO SHOW THE RISE IN BRAKE PIPE PRESSURE AND TIME OF RELEASE ON A 80 CAR TRAIN AFTER A 20 LB BRAKE PIPE REDUCTION, BRAKE VALVE HANDLE PLACED IN FULL RELEASE POSITION FOR 15 SEC. THEN RETURNED TO RUNNING POSITION.
70 LB. BRAKE PIPE PRESSURE
100 LB. MAIN RES. PRESSURE
75TH CAR
50TH CAR
25TH CAR
1ST CAR
SECONDS
T.V. Released
69½ sec.
19 sec.
72½ sec.
20 sec.
18 sec.

FIG. 25.

Figs. 26 and 27. These charts are similar to those preceding, except that the brake pipe pressure has been reduced below the equalizing point. This is an operation that is very likely to be prolific of damage, particularly break-in-twos, as it is not difficult to raise the brake pipe pressure up to that of the auxiliary reservoirs at the head end of the train, but it is impossible to raise the brake pipe pressure at anywhere near the same rate at the rear of the train, consequently, there is much greater interval of time between the release of the forward brakes and the rear brakes than where the brake pipe pressure has not been reduced below that of the auxiliary reservoir. In fact, so long as an interval exists that the engineer is very likely to help the retardation still going on on the rear, break the train in two by opening the throttle, if the train is still running and, if standing, by starting the forward end of the train before the brakes have released at the rear. After the brake pipe pressure has by any means fallen below that of the auxiliary reservoir a very long period of time, comparatively, must elapse before the brakes will release at the rear end of the train. This is apparent from an inspection at the rate of rise of brake pipe pressure, as shown on the charts, which is not more than 8 pounds per minute after the forward triple valves have gone to release position; consequently if the brake pipe has been reduced 10 pounds below that of the auxiliary reservoir about 1 minute must elapse before it is certain that the brakes have released.

A glance at Fig. 27 will show that after such an over reduction that part of the train ahead of the 25th car was running free before even the 50th car had started to release.

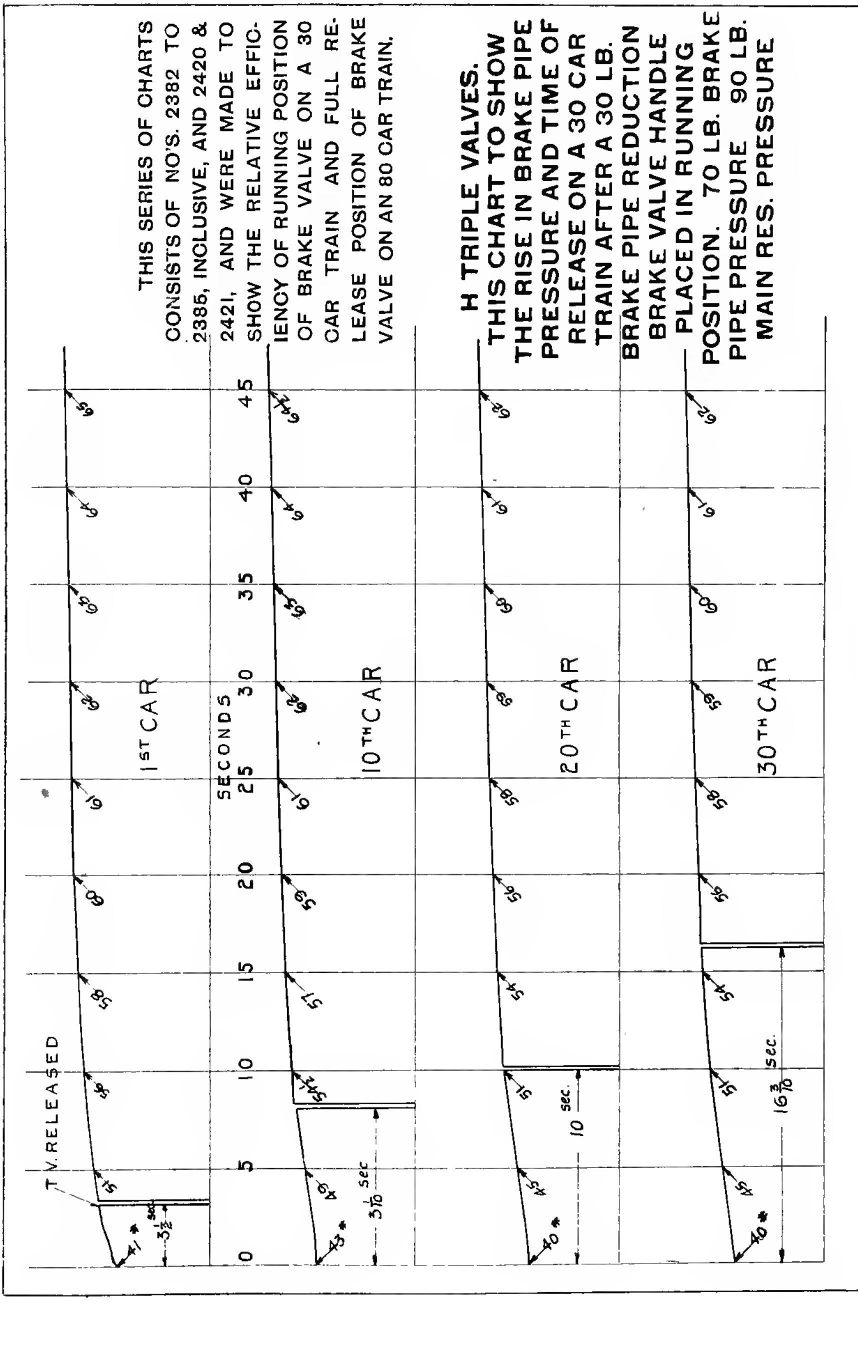

THIS SERIES OF CHARTS CONSISTS OF NO'S. 2382 TO 2385, INCLUSIVE, AND 2420 & 2421, AND WERE MADE TO SHOW THE RELATIVE EFFICIENCY OF RUNNING POSITION OF BRAKE VALVE ON A 30 CAR TRAIN AND FULL RELEASE POSITION OF BRAKE VALVE ON AN 80 CAR TRAIN.
H TRIPLE VALVES.
THIS CHART TO SHOW THE RISE IN BRAKE PIPE PRESSURE AND TIME OF RELEASE ON A 30 CAR TRAIN AFTER A 30 LB. BRAKE PIPE REDUCTION BRAKE VALVE HANDLE PLACED IN RUNNING POSITION. 70 LB. BRAKE PIPE PRESSURE 90 LB. MAIN RES. PRESSURE
T.V. RELEASED
1ST CAR
10TH CAR
20TH CAR
30TH CAR
SECONDS
0
5
10
15
20
25
30
35
40
45
$3\frac{1}{2}$ sec
$3\frac{1}{10}$ sec
10 sec.
$16\frac{3}{10}$ sec.

Fig. 26.

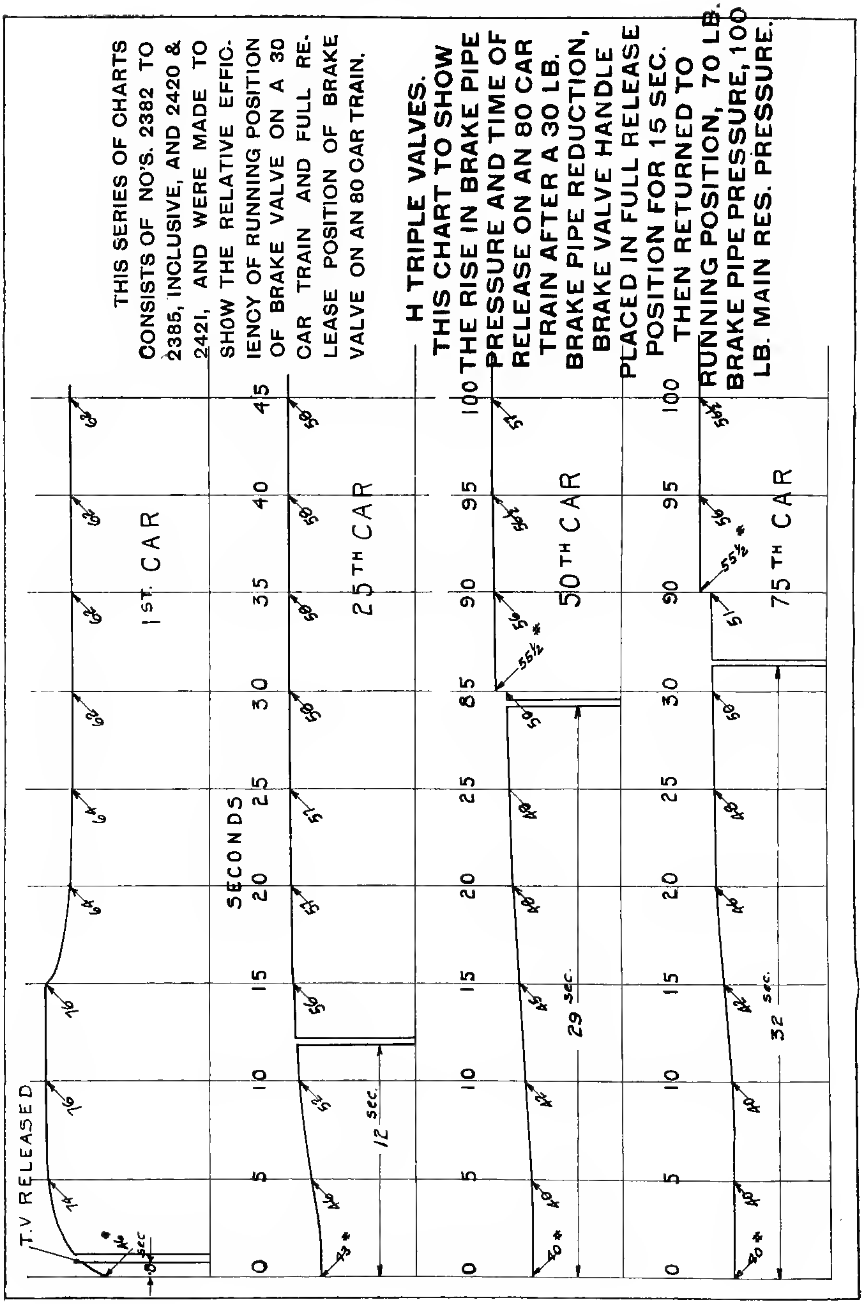


FIG. 27.

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The Air Brake as Related to Progress in Locomotion

BY

WALTER V. TURNER

Being a Paper Presented Before The Franklin Institute
Philadelphia, Penna.

November 17th, 1910

WESTINGHOUSE AIR BRAKE COMPANY
PITTSBURG, PENNA.

PREFACE

The following paper was presented by Mr. Walter V. Turner, Chief Engineer of the Westinghouse Air Brake Company, Pittsburg, Penna. at the meeting of the Mechanical and Engineering Section of the Franklin Institute at Philadelphia, Thursday, November 17, 1910.

The primary object of this paper is to present, in logical sequence, for the information of railroad operative officials and others interested in mechanical progress in general, but not directly concerned with the technical side of the subject of air-brakes, the reasons for, and results accomplished by, the various forms of air-brake equipments for steam road service which have been envolved to meet the successive advancements in the transportation facilities of the country.

Inasmuch as the vital and complementary relationship existing between developments in motive power and rolling stock equipment and in the apparatus for controlling such equipments when in motion, is often overlooked, we take pleasure in assisting in the wider distribution of this discussion of the subject, particularly in view of the recognized high standing of the body before which it was presented, and the appreciation with which it was there received.

WESTINGHOUSE AIR BRAKE CO.

PITTSBURG, PA.,
March, 1911.

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THE AIR-BRAKE AS RELATED TO PROGRESS IN LOCOMOTION.

BY

WALTER V. TURNER,

Chief Engineer, Westinghouse Air-brake Co , Pittsburg Pa.

EVERY moving body is capable, by virtue of its motion, of doing an amount of work before its motion can be diminished or stopped, which is directly proportional to the weight of the body and to the square of the speed at which it is moving. In the case of a vehicle, means must be provided which will permit this work to be done harmlessly and in a proper and predetermined manner. Otherwise the element of danger involved increases so rapidly with the weight and speed of the vehicle that locomotion, except in its most primitive stages, is prohibitive. The development of locomotion and consequently of transportation is, therefore, dependent in no small degree upon a like or even superior progress in the art of controlling vehicles in motion.

The laws according to which this art progresses can be determined only by following the successive developments which have been made in train control apparatus. This will be treated briefly in what follows, dealing primarily with the principles upon which such apparatus must operate, the methods, both theoretical and practical, by which these principles have been and are being applied to the problem in hand, and the funda-

mental conditions of service which fix the requirements that must be satisfied by a reliable and practicable device of this character.

PRIMITIVE VEHICLE BRAKES.—Knowing that the ancients travelled extensively, and that the great empires of history moved large armies over the then-known world, accompanied by trains of baggage wagons and war machines, it is natural to suppose that the necessity for retarding those vehicles must have been plainly manifested. But as a matter of fact, the first suggestion of this necessity by the use of a practical mechanism designed for the purpose does not appear to have been more than 250 to 300 years ago. The primitive carts and wagons which were used in agricultural work, and in connection with the transportation of baggage and supplies for armies, were of such construction that the natural resistance to rotation of their wheels was quite sufficient to bring them to a stop upon ordinary roads; and in cases of steep grades it was always easy to chain a log or stone (Fig. 1) to the back of the wagon, so that by dragging it over the ground the speed of the vehicle was checked.

Indeed, to find the time when the question of braking first came into prominence, it is necessary to go no further back than the period when highways became sufficiently well made and maintained as to admit of a heavy vehicle being drawn over them at comparatively high speed.

A remarkable adherence to one basic combination of elemental parts, of the same general character and function, is to be observed in even the earliest types of brake apparatus. This extends from the simplest primitive forms through the entire progress of the art until they are found to-day, associated, it is true, with great specialization and complexity of detail, but still having essentially the same fundamental components.

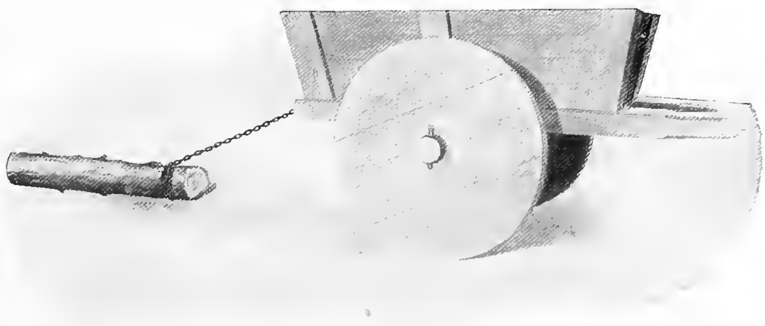
This is natural, because, as the moving vehicle must be controlled by self-contained apparatus, it was first necessary to devise means whereby a source of energy or pressure, located on the vehicle, might be made to generate retarding force, opposed to the motion of the vehicle.

It is easy to see that the revolving wheels and axles offer the convenient and practicable opportunity required, and, consequently, it is not surprising to find that practically all brake

devices, no matter how widely diversified in details, have one feature in common. This consists of a block or brake-shoe, as it is called, so located that it may be pressed against the wheel tread with more or less force as may be necessary. This develops a frictional force or pull between the relatively stationary shoe and the revolving wheel which, so long as it does not exceed the "adhesion" of the wheel to the rail or roadway on which it rolls, tends to retard and finally stop the motion of the wheel and thereby of the vehicle itself.

It can be proved by experiment that the "adhesion" of a wheel to a rail while rolling (static or, more properly, rolling friction) is greater than the frictional force at this point when the wheel is sliding (kinetic friction). Therefore, the maximum

FIG. 1.



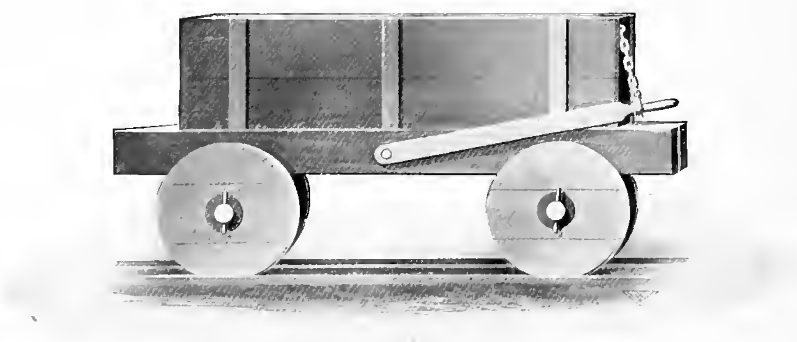
The drag.

retardation on the vehicle as a whole is obtained when the brake-shoe pressure is such as to produce a frictional force at the shoe nearly but not quite sufficient to cause the wheel to slide. This explains why wheel sliding must be avoided for theoretical as well as practical reasons.

EARLY RAILWAY BRAKES.—One of the earliest and simplest means of retarding the wheels of a vehicle in this way was forced by a change in existing conditions, just as the many subsequent changes in methods of locomotion have been responsible for the perfection of the brake as we know it today. About the year 1630 an enterprising mine owner at Newcastle-on-Tyne, finding the roads between his mine and the river so bad as to seriously interfere with the hauling

of coal, conceived the idea of laying wooden rails in the road and running his cars thereon. The tractive effort of these cars was thereby so much decreased that the necessity of some contrivance to check their speed was at once apparent and brought out simple forms of brakes. One of these forms consisted of a metal-tipped beam which was fastened to the frame of the car in such a way as to scrape along in the ground at the side of the track. Another form was a simple lever pivoted to the side, near the centre of the car, and ordinarily held up by a chain, which, when desired for use, could be liberated and pressed by hand or foot against the top of the wheel, as shown in Fig. 2.

FIG. 2.



Primitive railway wagon brake; lever on top of wheel, used in New-Castle-on-Tyne, 1630.

Many other simple devices of like nature were adopted by such rail- or tram-roads as then existed, which require mention only to point out that all made use of a block or shoe forced against the tread of the wheel either directly, or through the medium of some simple combination of rods and levers, whereby the strength of the man applying the brake might be augmented or multiplied (Fig. 3).

THE STEAM-BRAKE.—As the speeds on these roads were generally quite low and the cars small enough to be drawn by draught animals, such devices served all practical purposes until the inauguration of a new order of things, by the advent of the steam locomotive. With the speeds and weights of cars which then had to be reckoned with it soon became evident

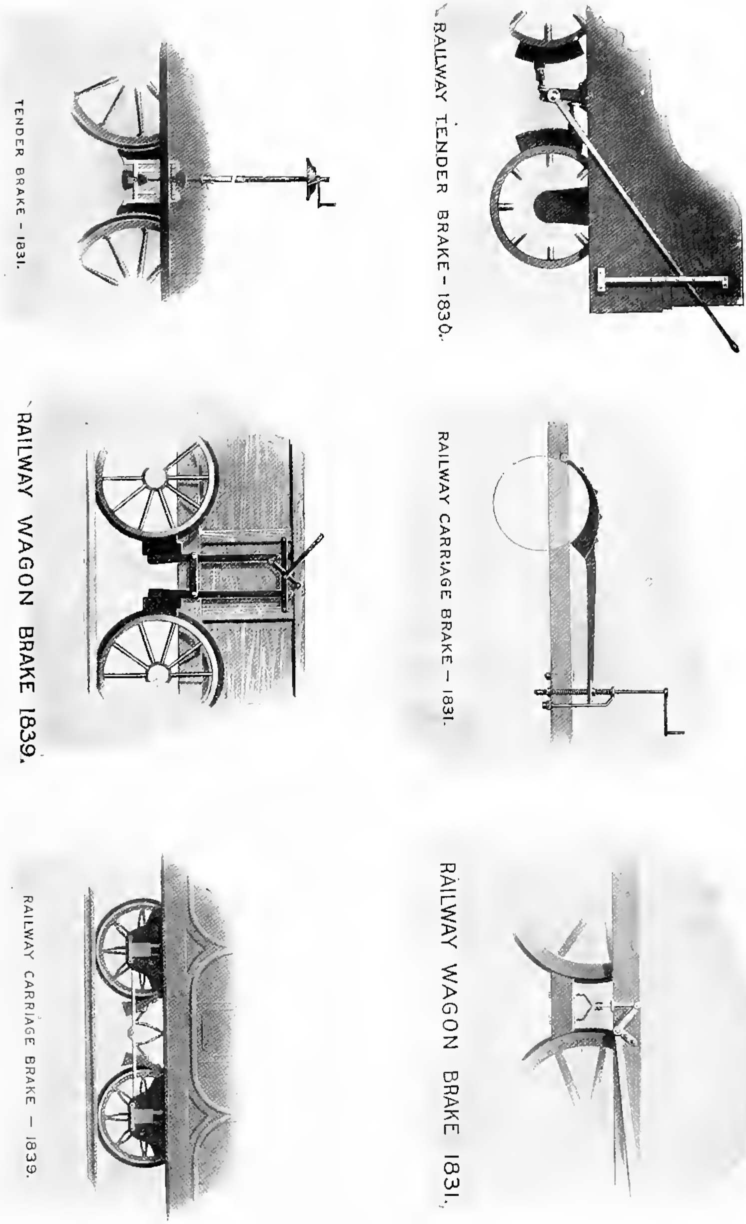
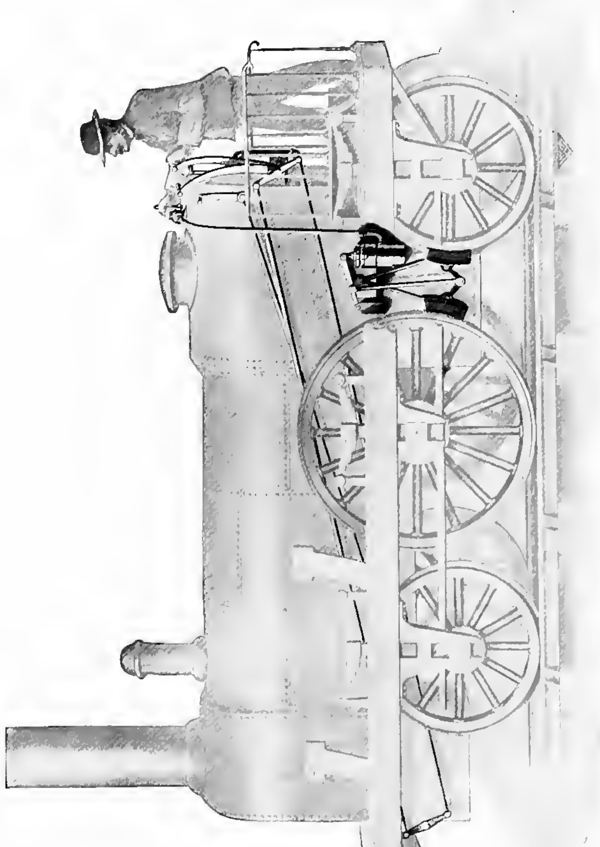


FIG. 3.

Simple and early types of hand-brakes.

that something better than a manually operated brake was needed. In 1833 Stevenson patented his steam-brake (Fig. 4), in which steam pressure, acting on a movable piston, was made to take the place of the hand-operated mechanism by which

FIG. 4



Stevenson's steam locomotive brake.

the force was applied through a system of rods, multiplying levers (and cams in this case) to the brake-shoe. In this first form of power-brake we have all the elements of a complete power-brake, viz.:

1. Source of power—steam.

2. Means whereby this power may be made to act upon the rods and levers of the brake rigging proper—a "brake"-cylinder with movable piston and rod.

3. Connecting rods and multiplying levers to transmit and increase the pressure exerted on the brake piston—called the foundation brake-gear.

4. Means for transmitting the force exerted through the foundation brake-gear to the wheels as retarding force or "pull"—this being the function of the brake-shoes as already explained.

In the case of the cars, the hand-operated brake, with various forms of foundation brake-gear, met all practical requirements for some time, though a general realization of the necessity for some form of power-brakes is attested by the fact that during the first 70 years of the Nineteenth Century about 650 patents were granted in England for various kinds of brakes for railroad service.

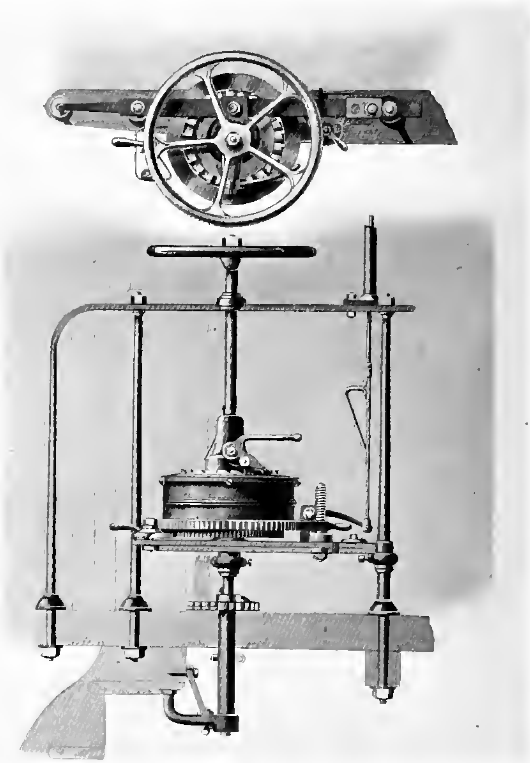
PNEUMATIC BRAKE.

The first pneumatic-brake was a vacuum-brake patented by James Nasmyth and Charles May in 1844. In 1848 Samuel C. Lister patented an air-brake having an axle-driven pump and suitable reservoir to be placed on the "Guard's Carriage," and suitable cylinder, pipe, and connections on the various cars to constitute a straight-air equipment much the same as that which followed many years after, except that it was designed to be operated by the guard and not by the engineer.

CONTINUOUS TRAIN-BRAKE.—Of course, the earlier types of hand-brakes underwent considerable improvement, but while the majority of passenger, as well as freight cars, were braked by hand, as more and heavier cars came to be handled in the same train, the necessity for a "continuous" brake or one capable of being put in action on the various cars comprising the train, at the will of the engineer himself, became more and more evident. Some of the various systems originating in this country were extensively tried and seemed to meet the conditions for which they were designed with various degrees of success. The "Creamer" brake (Fig. 5), which was brought into use in 1853, consisted of a large spiral spring attached to the brake-staff, at the end of the car, and

which was wound up by the brakeman immediately after leaving a station. Attached to the mechanism was a cord which ran through the train to the engineer's cab, and the brake was so designed that when the engineer pulled the cord, the coil springs on each vehicle were released and these at once wound up chains leading to the foundation brake-gear, thereby bringing the brake-shoes against the wheels.

FIG. 5.



Creamer brake, 1853.

The "Loughridge Chain-Brake" (Fig. 6), which came into use in 1855, consisted of a system of rods and chains continuously connected throughout the train, as follows: On each vehicle were two pairs of small pulleys, each pair sliding toward the other upon an iron framework, but held apart by a spring; to

each pair was connected a top rod leading to the foundation brake-gear. Upon the engine was placed a drum connected by

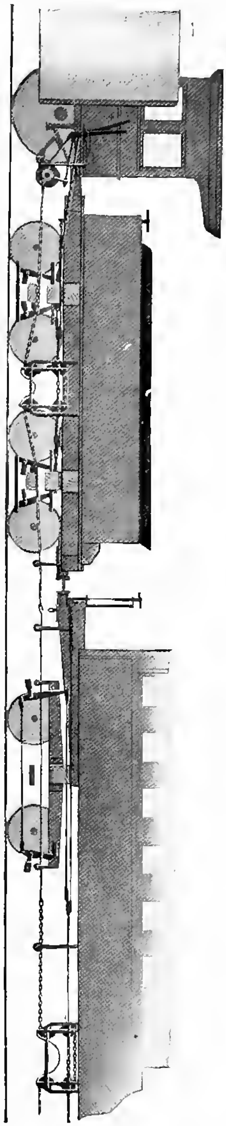


FIG. 6.

Loughridge chain-brake, 1855.

a worm and gear to a small friction wheel; when a lever in the engineer's cab was pulled this friction wheel was brought

into contact with the periphery of one of the driving-wheels, thereby causing the drum to wind up the chain and shorten its length throughout the train; in so doing the pulleys upon each vehicle were brought closer together, thereby applying the brakes.

In addition to the above, various forms of continuous brakes, other than air-brakes, were tried to a greater or less extent from time to time. Among these may be mentioned the Smith Vacuum-Brake, the Westinghouse Vacuum-Brake, the Eames Vacuum-Brake, the Fay Mechanical-Brake, the Clark & Webb Chain-Brake, the Barker Hydraulic-Brake, the American Buffer-Brake, the Widdifield & Button Friction Buffer-Brake, the Rote Buffer-Brake, the Carpenter Electric Air-Brake, and the Card Electric-Brake. From the length of this list it will be seen that to give an adequate description of these various systems would be to occupy with matter of purely historical or curious interest, valuable space and the time of the reader which promise already to be overtaxed by the demands of modern practice and recent development.

While these types of brakes were the result of much ingenuity and skill, and attained to a degree of success sufficient to prove the necessity for, and advantage of a reliable and efficient continuous brake, none of them satisfied enough of the fundamental requirements of a practicable, continuous brake to result in their universal acceptance as a standard in this country.

THE AIR-BRAKE—STRAIGHT AIR TYPE.—The first steps of the complete solution of the problem were taken, and a new line of development opened up, by the genius of Mr. George Westinghouse, who, in 1869 took out his first patents for the Westinghouse Non-Automatic Air-Brake, since generally designated as the "Straight Air-Brake."

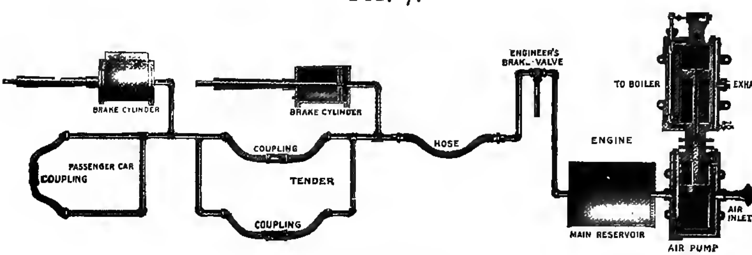
The source of power adopted for this system was the expansive force or pressure of compressed air, obtained from a steam actuated air-pump placed upon the side of the engine, and a reservoir in which the compressed air could be stored. A pipe line from the reservoir was carried throughout the length of the train, connections between vehicles being made by means of flexible hose and couplings. Each vehicle was provided with a cast-iron cylinder, the piston rod of which

was connected to the brake-rigging in such a way that when the air was admitted to the cylinder the piston was forced out and the brakes thereby applied. A three-way cock or valve located in the engineer's cab by means of which compressed air could be admitted to the train pipe and thus to the cylinders on each car to apply the brakes; or the air already in the cylinders and train brake pipe could be discharged to the atmosphere, thus releasing the brakes.

An early form of the Straight Air-Brake is shown in Fig. 7. The air-pump is one of the first forms to come into general use, the so-called "trigger" or "jigger" valve motion and octagonal piston rod being features of particular interest.

This type of apparatus has many good qualities and a very large degree of flexibility, that is, the increase or decrease of

FIG. 7.



Straight air-brake.

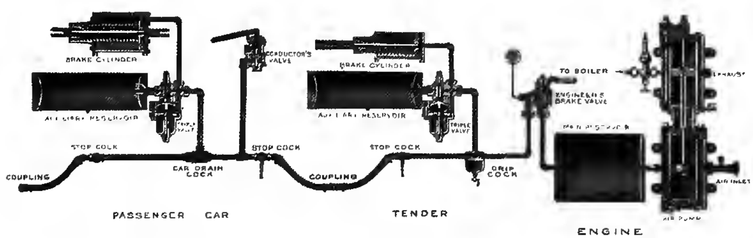
the pressure or braking power, so-called, was under the control of the operator to a very marked degree, but had shortcomings which made it unsuitable for use on trains of any considerable length on account of the time required to apply and release the brake and the unequal braking effort throughout the train. More important still, the factor of safety was low; as no warning was given in the event of the hose coming uncoupled, and a parted train meant no brakes. Thus it is seen that it lacked the first essential of an efficient brake, which is, that it must be its own "tell-tale." That is, if an accident occurs to the system, it must result in a brake application instead of a loss of the brake.

PLAIN AUTOMATIC AIR-BRAKE.

In the natural process and development of railroads, the requirements became more exacting and it was evident that the

straight air-brake was not only unsuitable for the reasons just mentioned, but that it lacked essential features. It became more than ever important that the brake must apply automatically, in case of the train parting. This was so fundamentally necessary that even if the flexibility of the straight air-brake had not already been lost to a large extent by the lengthening of the trains, it would have had to be abandoned because of the infinitely greater safety inherent in a brake of the automatic type. Therefore, the straight air-brake, having served its purpose as an advance agent of something better, gave way to the automatic-brake, which afterwards came to be called the "plain automatic-brake," to distinguish it from a later type that locally reduced the brake pipe pressure, thus producing what is called "quick action."

FIG. 8.



The "Westinghouse" plain automatic air-brake, 1872.

The first form of this brake, probably the greatest advance ever made in the art, was invented and introduced by Mr. George Westinghouse in 1872 (Fig. 8).

The automatic feature resulted from the obtaining of an indirect application of the brakes through the medium of a valve device called a triple valve, and an auxiliary storage reservoir, which were added to the brake cylinder on each car. All of the triple valves were connected together by a continuous pipe, called the brake-pipe, with flexible connections between the cars; this pipe being charged with air whenever the brakes were in operative condition. By this means, the auxiliary reservoir was charged with compressed air for braking purposes on the vehicle to which it was attached; therefore, it was no longer necessary to transmit the air from the locomotive to the vehicle when

an application of the brakes was desired. The triple valve is the essential mechanical element in such a system, possessing the three functions of charging the auxiliary reservoir and of applying and releasing the brakes in accordance with variations in the air pressure carried in the brake pipe; the medium for producing such operations as desired, being, for all general operations, a manually operated brake valve on the locomotive.

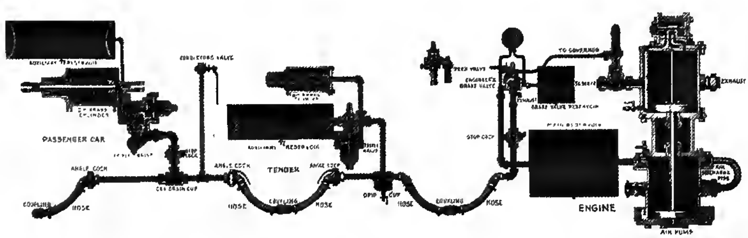
By means of this valve the engineer could apply the brakes either to a part of their capacity, and by steps or graduations, or fully, by a continuous decrease of the brake pipe pressure. but he had no control of the release of the brakes (as with the straight air). The automatic brake releasing locally on each car, while the release of the straight air-brake was controlled on the engine. Therefore, one of the elements of flexibility possessed by the straight air-brake was lost, but, as has been said, this feature had already been very much reduced in value by the lengthening of the train.

Thus, through the instrumentality of the triple valve, the air-brake became automatic, which term applies to that *application* of the brakes which occurs through any material depletion from any cause of brake-pipe pressure, either at the will of the engineer, by hose parting, burst hose, leakage, or at the instance of the train crew, so that this system very materially increased the factor of safety and permitted the use of air-brakes on longer passenger trains, and on the already existing freight trains, in a way that was not possible with the straight air-brake equipment.

QUICK-ACTION AUTOMATIC AIR-BRAKE.—This plain automatic brake was a great improvement in many respects over the straight air-brake, but chiefly from an emergency or safety stand-point, for much of the flexibility (that is, the ability of the operator to increase or decrease the cylinder pressure at will and for any desired number of times in rapid succession) for ordinary service brake operations had to be sacrificed. This brake served the purpose fairly well while trains were short, and speeds, weight and frequency low, but as these factors changed, *its* limitations became more and more apparent, particularly with reference to emergency operation. The application was too slow with long trains, *and for* reasons differing only in degree from those which had affected the straight

air-brake. Thus when a quick application was attempted, the shocks were great, nor was the stop as short as required. The reason for this slowness of operation was because the air in the brake pipe could not be quickly and uniformly reduced throughout its whole length; this, because of increased volume, frictional resistance, and the necessity of its travelling to the one outlet, which was through the brake valve at one end of the train. This limitation was overcome by the invention (in 1887) of the "quick action" triple valve and the equipment with which it was used came to be known therefore as the Quick-Action Automatic-Brake (Fig. 9). The "quick-action" triple valve was identical with the plain triple valve as far as service operations were concerned, but differed from it in emergency in that

FIG. 9.



The "Westinghouse" system quick-action automatic-brake, 1887.

it automatically vented air from the brake pipe locally on each car. The rapid brake pipe reduction thus resulting is transmitted to the next triple valve and from it serially in the same manner to all the valves in the train, thereby reducing the time of full application to about one-sixth of what is inherent with plain triple valves on a 50-car train, and shocks were therefore correspondingly lessened and stops shortened. The reason for this is that the brake pipe reduction with the plain triple valve took place at only one point in the train instead of fifty as with the quick-action valve.

The feature of serial venting of the brake pipe was so important that a second feature of this brake system, which the first mentioned made possible, was, and is to-day, overlooked by many, and perhaps is often not rated at its true value. This

feature was the then possible attainment of a different, and higher, braking power for emergency than for service applications. Up to this time the cylinder pressure, or retarding force, attainable had been the same for both service and emergency applications, but now, since the brake pipe pressure vented could be, and, as a matter of fact, was vented into the brake cylinder with one form of the device, the pressure therein was materially increased whenever quick action took place.

From this it will be seen that to the automatic and graduating features of the brake two others were added, namely, serial quick action and difference or increase in braking power between service and emergency applications. All four of these are now generally recognized (though often not appreciated as they should be) as being fundamentally essential in a brake worthy the name. Moreover, these four features have had and still have great possibilities of extension and development. Attention should be called again to the wonderful adaptability of the original combination of brake cylinder, triple valve, and auxiliary reservoir to the ever-increasing need of more powerful, and what naturally follows, a more flexible brake. *It is truly remarkable that through all subsequent improvements not one of the original functions of the triple valve has been discarded, but that they have been extended and expanded and many new functions added.*

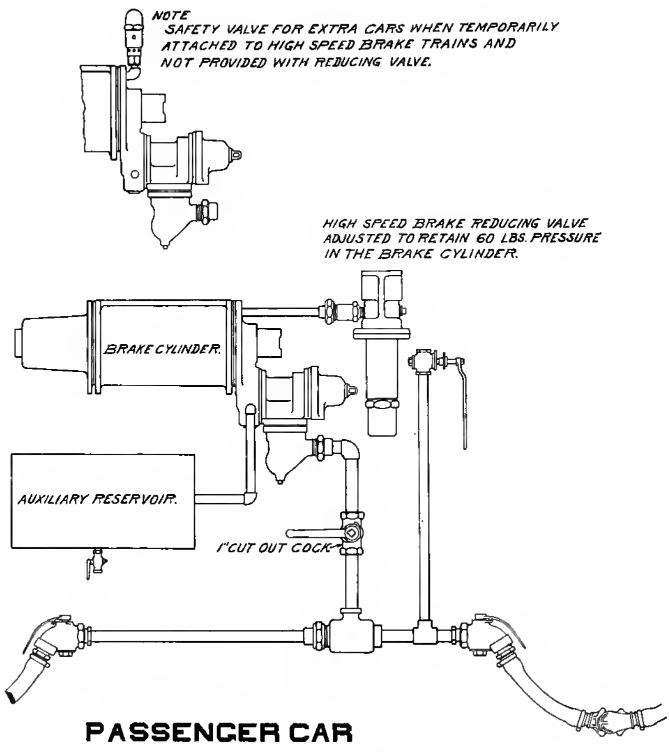
So far, the apparatus employed was the same for both passenger and freight cars, but the still greater frequency of trains, heavier vehicles, and higher speeds made it necessary to provide means whereby a still greater stopping power for passenger service might be available when needed, particularly for emergency applications. This was possible only by increasing the air pressure, since any other method would have made the brake too severe for low speeds; in other words, the percentage of braking power per pound of cylinder pressure was already as great as practical operation would permit.

THE HIGH-SPEED BRAKE.

It was thought, however, that to increase the brake pipe pressure sufficiently to give the desired braking power would result in unpleasant or dangerous shocks, slid and flattened wheels, and other damage from the high brake-cylinder pressure

obtainable; therefore, this was not done until the valve known as the "high-speed reducing valve" was perfected in 1894. The principles utilized by this type of apparatus had been thoroughly demonstrated by the classic Westinghouse-Galton tests in England in 1878. These tests showed that, while the adhesion between the wheel and the rail,—which causes the wheels to

FIG. 10.



High-speed passenger brake.

persist in their rotation,—is practically uniform at different speeds, the friction between the brake-shoe and the wheel,—which acts as a resistance to the rotation of the wheel, and thereby stops the train,—is considerably less when the wheels are revolving rapidly than when they revolve slowly. It was thus demonstrated that a greater pressure not only could be safely applied to the wheels by the brake-shoes, at high speeds, but also that such considerably greater brake-shoe pressure *must* be

applied to the wheels at high speeds, in order to then resist the motion of the train as effectively as it is resisted with a more moderate brake-shoe pressure at low speeds. This was accomplished by the use of a higher brake pipe air pressure with the standard Quick-Action apparatus, with only the addition of a High-Speed Reducing Valve attached directly to the brake cylinders. This device was designed to limit the brake-cylinder pressure obtainable during a service application of the brakes to what was considered safe and necessary, but when an emergency application of the brakes was made, to permit the brake-cylinder pressure to rise .to a considerably higher value than the maximum permitted in a service application, and then to cause a gradual reduction of brake-cylinder pressure, quite slow at first, but becoming more rapid, so as to proportion, as far as possible, with such a device working on a fixed range, the blowdown of brake-cylinder pressure to the reduction in speed as the stopping point is approached. Superior stopping capacity was obtained as already stated, by increasing the brake-pipe air pressure from the generally adopted 70 pounds, as used with the Quick-Action Brake equipment, to 110 pounds, which in emergency applications and with the sizes to brake-cylinder then in use would give about 85 pounds cylinder pressure instead of about 60 pounds, or, in other words, raise the nominal percentage of braking power from 90 to 125 per cent. of the weight of the vehicle.

With this improved equipment when an emergency application was made, full cylinder pressure (85 pounds) was quickly obtained, but was automatically reduced to 60 pounds and held at this point by means of the automatic reducing valve. Thus, if the stop was long enough, the initial nominal percentage of braking power was 125 per cent., while the final was 90 per cent., but the actual retardation of the train kept fairly constant due to the difference in the retarding power of the shoes at high and low speeds already mentioned. Though the coefficient of brake-shoe friction was known to be less at high speeds than at low speeds, it was predicted by many that much wheel sliding would result from raising the nominal power above 100 per cent. of the light weight of the car, but, on the contrary, wheel sliding was lessened and naturally so when the situation is analyzed.

In service applications, the opening from the reducing valve was larger than in emergency application so that if such a reduction of brake-pipe pressure was made as would cause the brake-cylinder pressure to rise above 60 pounds, the reducing valve would open and vent the air, which otherwise would cause an undesirably high brake-cylinder pressure, to the atmosphere.

This combination, with the quick-action triple valve, is known as the High-Speed Brake, and is illustrated in Fig. 10.

RECENT DEVELOPMENTS IN TRAIN BRAKE APPARATUS.

The typical brake equipments which have been mentioned, namely: straight-air, plain-automatic, quick-action-automatic and the high-speed brake, mark epochs during which the respective equipments were each able to successfully meet the traffic requirements existing for the greater part of the periods during which they were supreme, but as the demands of service became steadily more severe, each in turn gave way to its successor, the improved equipment in each case being in its turn satisfactory for such a time as the conditions which brought it into being were not greatly changed.

This growth, it will be noted, was along lines of improving the degree of efficiency of the fundamental functions of the original plain triple valve, either by increasing the air pressure carried for braking purposes, or by the aid of additions to the valve structure itself, or by the attachment of additional devices to existing apparatus, or by combination of two or more of the expedients just mentioned.

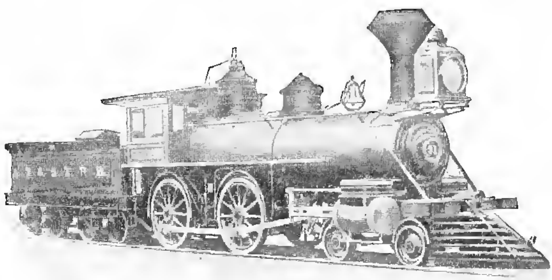
With the high-speed brake, the practical limit to improvement along such lines was believed to have been reached. For some time little or no improvement was thought possible, and this was indeed a fact, so far as further progress along lines previously followed was concerned, for two reasons. (1) About all was then being obtained from the old type of brake that could be gotten from it with the mechanism and arrangement of apparatus then existing. (2) New conditions requiring more specialized apparatus and refinement of the service and emergency features of the brake, as well as of the safety and protective features, began to develop with a rapidity which made it evident that a turning point had been reached.

As a matter of fact, it was rapidly becoming apparent, not

that the air-brake had advanced relatively to the requirements, but that it had not kept pace with the developments of locomotion. In other words, that even the most efficient brake of to-day is, at its best, not able to control and stop a train in the same distance as when the weight and length of the train was less than one-fourth of that to-day. That we have done as well as we have will be appreciated when it is considered that the length of the trains and the volume of air employed have rendered this vastly more difficult, as to service control, and the weight (which involves many factors) to the extent that it would require at least twice the distance in which to stop if the old brake had to be used with present-day conditions.

In addition to the increased weight and speed of trains,

FIG. 11.



American type of locomotive, 1879.

there were, of course, increased number of parallel tracks and frequency of trains. These always bring with them braking problems quite as difficult of solution, and as necessary to be solved, as those which proceeded them, particularly as the tendency is to neutralize or lower the value of many of the factors involved in producing and realizing retarding forces.

It is difficult for one who has not given the subject careful thought to realize the great changes in railroad equipment and operative requirements which have taken place since the introduction of the air-brake, but it is only necessary to review briefly these past and present conditions in order to appreciate the necessity for a similar development and improvement of the apparatus used for controlling trains under these new conditions.

The following comparative tabulations comparing the conditions existing from 15 to 20 years ago and those of to-day with regard to extent of territory covered, capital involved, traffic handled, and so on, will perhaps illustrate the conditions that now have to be faced better than the mere statements which have just been made.

RAILROAD DEVELOPMENT FROM 1889 TO 1909.

	1889	1909	Increase, per cent.
Miles of line	153,385	234,182	52.7
Miles of track	195,958	340,000	73.5
Net capital, etc	$7,366,745,000	$13,508,711,000	63.3
Passengers carried	472,171,000	880,764,000	86.5
Tons freight carried	539,639,000	1,486,000,000	175.3
Locomotives, number	29,036	57,220	97.0
Freight cars, number	829,885	2,113,450	154.6
Employees, number	704,743	1,524,000	116.2
Employees, compensation	$389,785,564	$1,003,270,000	157.4
Electric railways		50,000	

Locomotives.—The weight on drivers has increased since the air-brake was invented, from 25,000 pounds to 400,000 pounds.

The drawbar pull of locomotive has increased, since the air-brake was invented, from 10,000 pounds to 100,000 pounds.

The total weight of locomotives at the present time is as high as 700,000 pounds.

Working steam-pressure has increased, since the air-brake was invented, from 125 pounds to 225 pounds.

Passenger Cars.—Weights have increased from 20,000 pounds to 150,000 pounds.

Freight Cars.—Light weight of car has increased from 12,000 pounds to 50,000 pounds.

Capacity has increased in the last twenty years from 40,000 pounds to 150,000 pounds.

Passenger Trains.—Schedule speeds have increased from 30 miles per hour to 65 miles per hour.

The energy contained in a five-car train of cars having an average light weight of 30,000 pounds per car, running at a speed of 35 miles per hour, is 6,200,000 foot-pounds; of cars having average weight of 127,000 pounds, running at 65 miles

per hour is 90,000,000 foot-pounds, or nearly fifteen times as much.

Freight Trains.—Train length has increased from 15 to 130 cars; total weight has increased from 300 to 4500 tons and in certain places in the country as high as 6000 tons.

To take an actual example illustrating what is involved in the handling of a modern high-speed passenger train, the following figures are taken from the official report of the Emergency Brake Tests carried on about a year ago by the Lake Shore & Michigan Southern Railway near Toledo:

LAKE SHORE EMERGENCY BRAKE TEST.

Types of vehicles used	Weights	
	Pounds	Tons
Locomotive—Pacific type	388,000	194.0
Buffet car	149,000	74.5
Dining car	140,000	70.0
Sleeping car average	125,000	62.5

ENERGY IN TEST TRAINS.

Make up of train	2 Loco.—10 Cars	1 Loco.—6 Cars
Train weight—pounds	2,068,000	1,180,000
Train weight—tons	1,034	590
Energy at 40 M. P. H., foot-pounds	116,816,000	66,595,200
Energy at 40 M. P. H., foot-tons	58,408	33,298
Energy at 60 M. P. H., foot-pounds	262,836,000	149,839,200
Energy at 60 M. P. H., foot-tons	131,418	74,920
Energy at 80 M. P. H., foot-pounds	467,264,000	266,380,800
Energy at 80 M. P. H., foot-tons	233,632	133,190

KINETIC ENERGY* IN TRAIN OF 2 LOCOMOTIVES, 10 CARS OF 75 TONS WEIGHT EACH—TOTAL TRAIN WEIGHT, 2,276,000 LBS. OR 1138 TONS.

Speed	40 M. P. H.	60 M. P. H.	80 M. P. H.
Foot-pounds	127,811,200	287,575,200	511,244,800
Foot-tons	63,906	143,787	255,622

* Kinetic energy in train of 2 locomotives, 10 cars of 75 tons weight each—at speed of 8c M. P. H. is sufficient to raise 1 ton to a height of over 48 miles.

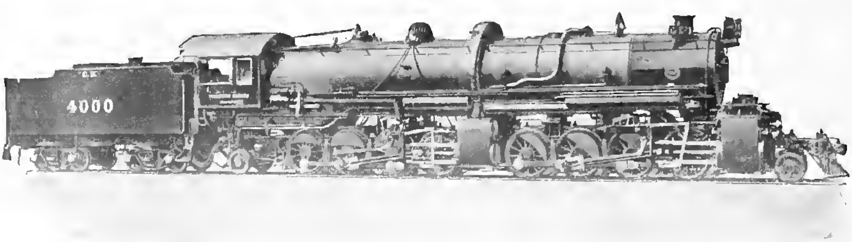
Figs. 11 and 12 present a tangible evidence illustrative of both extremes of the locomotive development indicated in the

tabulations just given. The view of the American type of locomotive (Fig. 11), representing standard practice of 1879 can, no doubt, be recalled by many of you, and is in marked contrast with the enormous Mallet Compound Locomotives (Fig. 12) now being introduced for heavy grade service in various parts of the country.

Similarly the progress in passenger car construction is graphically illustrated by comparing the typical passenger car of 1872 (Fig. 13), with the modern all-steel Pullman cars (Fig. 14), which are being built at the present day.

All the figures which have been given report the maximum conditions of past and present-day practice. As the application of the air-brake has made this enormous increase in weight of vehicles, speeds and length of trains possible, it is fair to assume

FIG. 12.



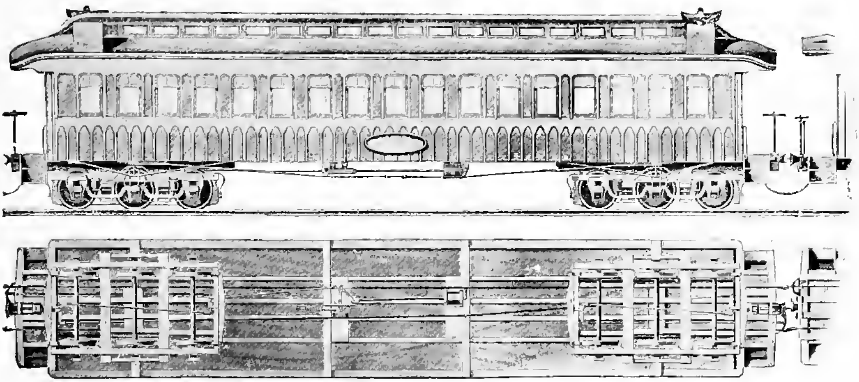
Mallet articulated locomotive—Atchison, Topeka & Santa Fe Ry., 1909.

that the stopping power of the brake should logically be increased in the same proportion so that the stop should be no longer now than formerly.

A concrete example will show forcibly just what this increase in weight and speed means to the operating department if it is to accomplish such an admittedly desirable and necessary result. Under the former conditions the factor of safety in train handling was none too large and it is therefore imperative that we should be able to control modern trains under present existing conditions at least as safely and efficiently as formerly. To do this for five 150,000 pound coaches, running at 65 miles per hour, it is necessary to provide means for controlling over 105,000,000 foot-pounds of energy as compared with about 6,000,000 foot-pounds which was all that the brake

of the early 70's was called upon to control with a train of five 30,000 pounds cars running at 35 miles per hour. When the locomotive used with each train is considered, the total

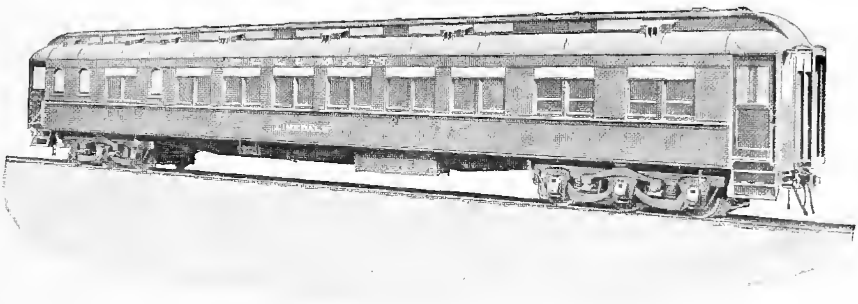
FIG. 13.



P. R. R. passenger car, 1872.

energy in the modern train becomes 162,000,000 foot-pounds, as compare with 9,800,000 foot-pounds, for the train of 1870. It is not surprising, therefore, that the air-brake art demands thoughtful consideration from trained and experienced minds if

FIG. 14.



All-steel sleeping car, 1909.

the railroad traffic of to-day is to be handled with a safety and efficiency even equal to that of the days when the total energy to be reckoned with was one-sixteenth as great. Here again is found another close resemblance between the conditions of ac-

celeration and deceleration, for while it is not especially difficult to increase the speed of a train from 30 miles per hour to 40 miles per hour, it requires the expenditure of a vastly greater amount of energy to increase its speed from 60 miles per hour to 70 miles per hour. In like manner, for any given increase in speed the additional amount of work required from the brake increases in geometrical, not arithmetical, ratio. If, therefore, the improvements for the heavier trains and higher speeds of to-day permit of stopping in about the same distance as could be done with the brake of forty years ago and the trains of that period, we should congratulate ourselves for having held our own.

The mere power necessary to accomplish this is indicated by the fact that the total maximum force exerted by the push rod of the 6-inch brake cylinder of the early equipment was 1700 pounds, while with the 18-inch brake cylinder used on the heaviest coaches, a maximum pressure on the push rod of 26,670 pounds is obtainable.

From the above it will be apparent that many features must now be considered which did not exist when the brake was first invented, particularly on the physical side of the problem. For example, the amount of work required per square inch of brake-shoe surface is vastly greater. This is a condition seldom noticed and yet of great significance, as the following comparison will show:

In the report of one of the earliest brake trials in the history of continuous brakes, made on the Midland Railway, near Newark, England, in 1875, and since known as the Newark trials (see London *Engineering,* June and July, 1875), the best brake performance recorded was by a train of fifteen, 21,000 pound (average), four-wheel carriages, fitted with a primitive form of the Westinghouse Automatic-Brake, one cast-iron brake-shoe being used on each wheel. The best stop was made from a speed of 52 miles per hour, the highest that could be obtained, in 18 seconds. This corresponds to the performance of 15.5 foot-tons (1 ton = 2000 pounds) of work per brake-shoe per second. In the classic Westinghouse-Galton Tests, which followed about three years later, the four-wheel experimental van used weighed 18,200 pounds, and was fitted with two brake-shoes per wheel, and from 52 miles per hour speed a

stop was made by the experimental van alone in 11½ seconds. Here the work done was only about 9 foot-tons per brake-shoe per second.

In 1875 the standard passenger coach used on the Pennsylvania Railroad weighed 39,300 pounds and had four-wheel trucks. To stop such a car from 52 miles per hour in 18 seconds required only 12.33 foot-tons of work per brake-shoe per second, or less than that required of the brake on the Midland train, although the Pennsylvania car weighed 18,300 pounds more. This is, of course, due to the fact that eight brake-shoes were available to do the work as compared with four on the Midland train. Contrast with the above a modern Pullman car weighing 160,000 pounds and having six-wheel trucks. Assuming that from a speed of 52 miles per hour that stop could be made in 18 seconds, the work done would be 33.5 foot-tons per brake-shoe per second, or over twice that of the Midland train, notwithstanding that there are twelve brake-shoes to do the work instead of four. But modern express train speed may be expected to run frequently as high as 75 miles per hour, and to make a stop from this speed in, say, 35 seconds (which would be about the best that could be expected of the modern brake equipment) would require 35.8 foot-tons per brake-shoe per second, or not much more than when a stop of 52 miles per hour is made in 18 seconds. But to have the same absolute safety under modern conditions as existed in 1875 would require the stop to be made in at least the same distance and time, and to stop a 160,000 pound car from a speed of 75 miles per hour in 18 seconds would require 69.6 foot-tons of work per brake-shoe per second or about 4½ times that in the case of the Midland train. (What this would be with four-wheeled trucks will be appreciated.) Even if two brake-shoes per wheel could be used instead of one there would still be over twice as much work to be performed by each brake-shoe per second if the trains of to-day at the speeds now attained in high speed service are to be relatively as safe as the trains of thirty years ago. Furthermore, the use of two brake-shoes per wheel is rapidly becoming a necessity, not only on account of the great amount of work to be performed by each brake-shoe, but also because the brake-shoe pressure required by modern conditions of high speeds and heavy cars are becoming so great that in emergency

applications a heavier pressure is brought to bear on the axle and journals by the brake-shoe acting on one side of the wheel only than is imposed by the weight of the car resting on that wheel.

The tremendous significance of this increase is but faintly appreciated by those who have not had occasion to investigate this aspect of the question. The cast-iron brake-shoe is to-day practically as it was thirty years ago. This brake-shoe must now do four times the amount of work by frictional resistance to the rotation of the wheel, as formerly. It may be suggested, "Why not quadruple the pressure per brake-shoe?" But it also must be remembered that when the brake-shoe pressure is multiplied by four, the actual retarding force is by no means quadrupled, for three vital adverse factors are being overlooked, viz., the effect of increased pressure, speed, and temperature on the coefficient of friction between the wheel and the shoe. Exactly how great an effect these may have depends, of course, on the conditions of the individual test considered, but that it is considerable is proven by the fact that a stop from a speed of 75 miles per hour in 35 to 40 seconds, instead of 18 seconds, is considered good, although we are to-day using about four and a half times as much pressure per brake-shoe as at the Newark trials.

It should be stated that in the above no account is taken of the rotative energy of the wheels. If this is considered, it is evident that the figure for the modern conditions will be still more in excess of those of the past, on account of the wheels being heavier and there being a greater number per vehicle.

Again, the difference in air pressure required to apply and release the brakes is by no means as easily obtained to-day as when trains were short. The air supply required for short trains with small brake cylinders was obtained with compressors of much less capacity than is now necessary to employ: witness, the 6-inch air compressor of the early days of the brake, with its capacity of not over 15 cubic feet per minute, as compared with the cross compound compressors now used, which have approximately 125 cubic feet capacity. The reason for this is apparent, for it required, not so very long ago, about 25 to 30 cubic feet for a full application; now 300 cubic feet is required.

In general, therefore, it may be stated that the brake which would satisfactorily meet the requirements of past conditions, falls short of the maximum efficiency which it should be possible to attain, in proportion to the increase of the requirements of present-day service over those of the past. The force of this is apparent when the same comparison is made between the locomotives and cars of the two periods. This review of the conditions and what is involved, which is by no means exhaustive, will serve to give an idea of the magnitude of the problem. How the various stages of this problem have been solved, as they presented themselves, will be shown best by a consideration of the features and functions of the improved brake apparatus that was developed to meet the conditions just explained.

CHARACTERISTICS OF IMPROVED BRAKE EQUIPMENTS.

While the fundamental service and emergency features of the Quick-Action Brake could not be departed from on account of the necessity for maintaining interchangeability of apparatus, and operative function, it was clear that in designing a brake to meet these new conditions, not only must the fundamental features of the old brake be improved to their highest possible efficiency, but new features must be added, some of which were inherently impossible if the design were carried on along the lines previously laid down.

With this as a point of departure, the development of the newer forms of locomotive, passenger and freight brakes was commenced and it may be fairly said that with the incorporation of the new features which will be explained in what follows, the air-brake entered upon a new era of its history as distinct from that which preceded, covering the progress of the art from the development of the plain automatic brake to the high-speed brake, as that era was distinct from those of the straight air-brake and of the hand-brake which marked the earlier history of the art.

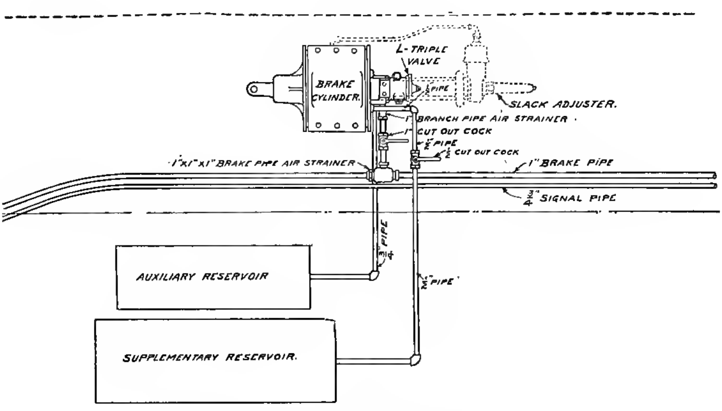
Briefly stated the recognition of the new principles required by the changed conditions referred to, led, in the case of the passenger brake, to the incorporation of the following features

in addition to those characteristic of the previous form of equipment: (See Fig. 15.)

1. Quick rise of brake-cylinder pressure so that the braking power may reach its maximum in the shortest possible time and thus begin to be effective in reducing the speed when at its highest value—and when the increase in distance run before coming to a stop is greatest for every second's delay.

2. Uniform braking power on all cars, irrespective of size of equipment and variation in piston travel, thus contributing largely to the convenience and comfort of passengers, as well

FIG. 15.



Improved passenger brake equipment, type "LN."

as making the brake more reliable and therefore easier to manipulate.

3. Maintenance of both service and emergency-brake cylinder pressures up to the capacity of the ample storage reservoirs of the cars. This is of the greatest advantage in overcoming the ever present and often serious depletion of brake-cylinder pressure by packing-leather leakage.

4. Predetermined and fixed limiting of maximum service braking power, without a safety valve or other blow-off device. This maintains the proper margin between the power of service and emergency applications and tends to reduce wheel sliding without wasting air and with a minimum of apparatus thus resulting in economy both of operation and maintenance.

5. Quick service feature to compensate for increased length of train and bring about more prompt, uniform and certain application of brakes.

6. Quick recharge of the auxiliary reservoirs to offset longer trains and larger cylinders and reservoirs and insure a prompt application of the brakes when desired and prevent the depletion of the auxiliary reservoir pressure.

7. Graduated release feature to add to the flexibility of the brake by making it possible to graduate the brakes off as well as on and so to handle the train more smoothly, with a greater saving of time, and a reduction in the amount of wheel sliding.

8. Much higher brake-cylinder pressure obtained in emergency for the same brake-pipe pressure carried, which pressure is maintained and retained during the complete stop, thus materially shortening the stops and adding greatly to the safety of the trains.

9. Automatic emergency application on depletion of brake-pipe pressure. This is a safety and protective feature of great value, in that it insures sufficient braking power being automatically obtained to bring the train to a stop in case the system is depleted below a predetermined pressure either by careless manipulation or accidentally.

10. Full emergency braking power at any time, thus placing the maximum stopping power the brake has to offer at all times ready for use by the engineer whenever an emergency arises, irrespective of what may have preceded.

11. Separation of service and emergency features so that the necessary flexibility for service applications can be obtained without impairing in the slightest the emergency features of the equipment and conversely, so that undesired quick action is practically impossible.

12. High maximum braking power secured with low total leverage, with correspondingly greater over-all efficiency of the brake.

13. Better mechanical design resulting in more uniform wear of parts and ease of access for removal or repairs.

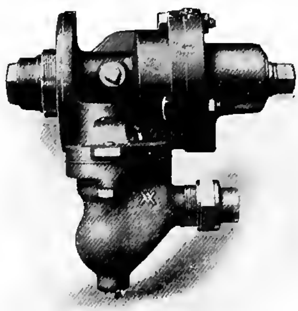
In the case of the freight brake, the change in the conditions which require a change in apparatus were in the direction of greatly increased length of trains, and difference between the

light and loaded weights of the cars. The features of the new freight brake were therefore developed with particular reference to those considerations as follows: (See Fig. 16.)

1. Ability to apply and release the brakes without fear of shocks, under conditions where they are certain with the old brake, gives an added value to all rolling stock.

2. As only a comparatively light reduction is required with the quick service valves to apply all the brakes and with uniform cylinder pressure, there is not sufficient braking power developed in any one part of the train to cause the slack to run in or out severely. On the other hand, with the old brake, a heavy reduction is required to apply the brake at the rear of a long

FIG. 16.



Type "K" freight triple valve.

train, the effect of which is to bunch the slack severely with consequent running out again as the brakes take hold at the rear and the draft springs recoil. As shock is the complement of time and the place where the retarding force is developed, it will be seen that shocks, due to brake applications, will be greatly reduced with the new valve, for while the time required to dissipate the energy of the moving train will be the same, the distribution of the braking power will be different, as it will be divided among all the vehicles in the train instead of first one end and then at the other.

3. Because more applications and release can be made in the same time with the new brake than with the old—much better control and safer operation of the long trains are obtained.

4. On account of the uniform release feature, and because a maximum or full service application of the brake is seldom required with the new brake, the release is more prompt and certain at the rear (which, as has been shown, is the vital place of a long train), and the number of "stuck brakes," flat wheels, and shocks are greatly reduced, particularly as no damage can be caused by the engineer opening the throttle before the brakes at the rear have released.

5. The uniform recharge feature assists in this, inasmuch as the number of "stuck brakes" (resulting from a re-application due to over-charging after a release) is reduced and more equal response of all the brakes secured for subsequent application.

6. The quick service feature makes possible much shorter stops, which is important at all times, but particularly where block signals are in use. This makes unnecessary quick action applications of the brake except in cases of actual danger.

7. The uniform release feature in grade work to a large degree acts as an automatic retaining valve, which is one of the factors in the increased control.

8. The uniformity of application and release tends to reduce the serious effects of the wide difference of braking power with loaded and empty cars in the same train.

9. That vital factor in train control, the personal equation, is made more uniform; as less skill and judgment is required to get good results, while lack of these cannot result in so much harm.

10. As the air required to obtain the same control is only one-third of that required by the old brake, there is much less danger of the supply being inadequate, and with brakes in a reasonably operative condition, there is more likelihood of the engineer stalling or stopping than of "losing his air."

11. Much shifting of lading and breaking-in-two now caused, independent of the brake, by stopping and starting, will be eliminated, as slow downs instead of stops can be made.

12. More tonnage can be handled, and at higher and more uniform speeds, with safety, than has heretofore been possible.

13. Accidents, due to broken wheels, will be fewer, as with the new valve each brake does nearer its share of the work; thus, the excessive heating, due to hand brakes being used, or a few brakes doing the work, no longer takes place.

14. (*a*) The old valves are greatly helped by the new ones when mixed in a train. (*b*) The new features are simply additions to the old valves, the fundamental operative functions and principles remaining the same as in previous forms.

15. With the empty and load brake, greatly increased tonnage can be handled, with equal or even more safety and for mixed empties and loads in the same train the elimination of damaging stresses due to inequality of braking power on empty and loaded cars. The characteristics of this equipment and its peculiar advantages merit a more extended description which will follow a little further on.

In the case of the locomotive brake, the new features characteristic of the improved equipment were naturally in part due to the necessity for bringing the locomotive equipment up to an equal efficiency with the improved passenger and freight brake apparatus as just outlined.

In addition, however, certain desirable operative features had long been recognized, but remained impracticable until the establishment of a new basis for design afforded an opportunity for including in a compact and mechanically satisfactory combination of parts, all that previous experience had shown to be desirable in an efficient locomotive brake (see Fig. 17). Briefly stated these are as follows:

1. Either entirely independent or simultaneous operation of the train and locomotive brakes as may be desired, thus permitting of much greater degree of convenience and flexibility in handling long trains, especially on grades, in switching, etc.

2. Maintenance of brake-cylinder pressure whether partial or full application, up to the capacity of the compressor, thus insuring that the desired amount of braking power on the engine will be obtained and maintained irrespective of the leakage which is so difficult to prevent in the case of locomotive brake cylinders especially.

3. Uniform brake-cylinder pressure in all brake cylinders on the locomotive, irrespective of piston travel, number of cylinders or leakage, thus doing away with the necessity for different size or type of operating mechanism for different sizes of cylinders or types of locomotives as well as insuring against variations in braking power due to differences in piston

travel, which must always be reckoned with on account of the brake-shoe wear or neglect in adjustment.

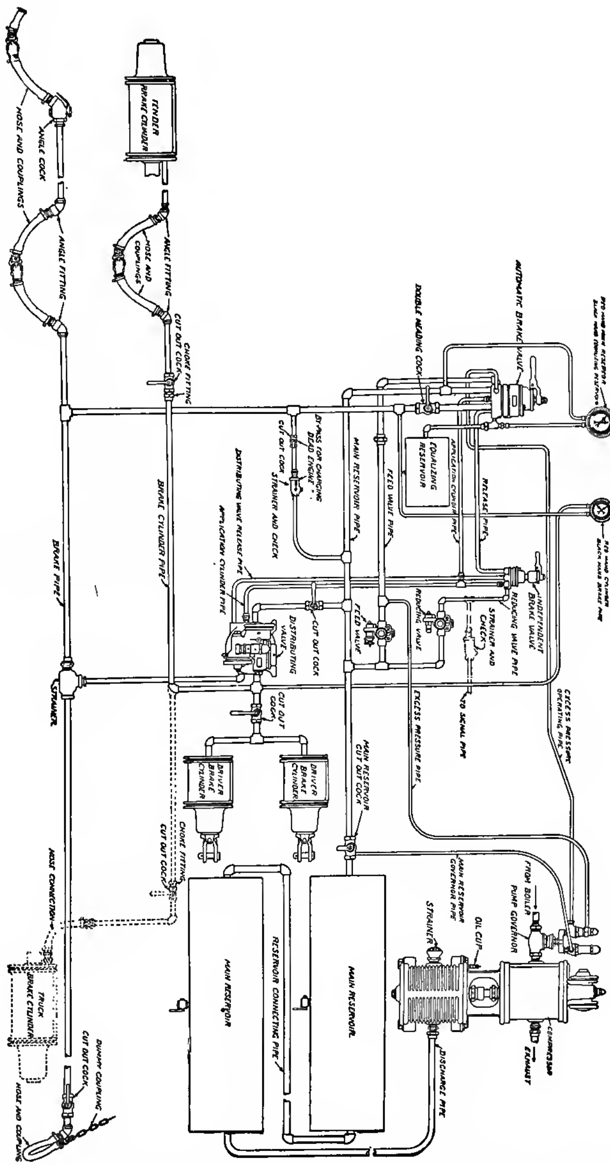


FIG. 17.

Piping diagram "ET" equipment.

4. Predetermined and desirable increase in emergency brake-cylinder pressure over the maximum obtainable in service, thus

securing for the locomotive brake equipment an advantage long recognized as fundamental for all car-brake equipments.

5. Automatic protection against loss of air required for braking due to brake-valve handle being left in lap position by mistake.

6. Graduated release feature for the locomotive brakes which will then work in harmony with the new graduated release type of passenger car brake.

That the above features are all in the direction of increased convenience, economy and safety in the handling of both passenger and freight traffic, is self-evident, but when it is further considered that these advantageous improvements have been incorporated in a combination of apparatus less complicated and

FIG. 18.

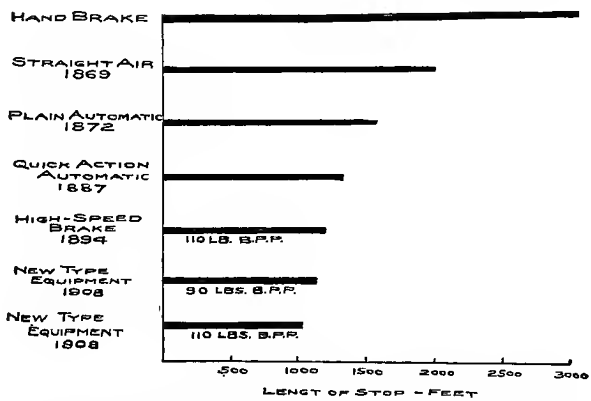
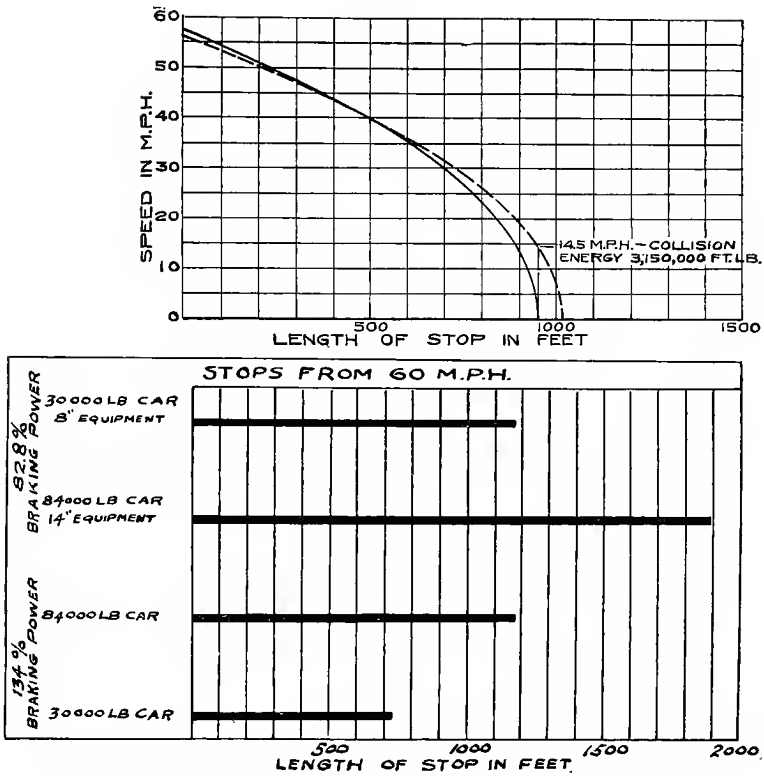


Diagram of development of air-brake efficiency since 1869.

with fewer number of parts than required by the old equipment at its best and that the mechanical design and arrangement of parts has been greatly improved with respect to minimizing the wear due to ordinary service and in increased ease of maintenance and repairs, it will be seen that the character and degree of the improvements which have been made are in accord with, and not antagonistic to, the demands of modern railroad service for apparatus of the highest efficiency coupled with a maximum of economy and a minimum of complexity.

To consider for a moment the quantitative results of the improvements which have been mentioned as evidenced by the comparative stopping distances of trains equipped with the types of brakes referred to. The diagram (Fig. 18), shows concretely

FIG. 19.



Comparative retardation curves and braking power chart for trains of 1875 and 1907.

Date	Speed in M.P.H.	Length of stop in feet	Time of stop in sec.	Weight of trains, tons	Work in ft.-tons performed by brakes			B. P., per cent.
					Total	Per sec.	Per brake-shoe per sec.	
1875	56.0	1020	22.0	227	23900	1086.4	14.70	82.8
1907	57.3	954	18.7	559	61300	3278.0	28.75	150.0

Dotted curve shows stop on Midland Railway, 1875, with the Westinghouse Automatic-Brake.

Full-line curve shows stop made on W. J. and S. R. R., 1907, with the Westinghouse "LN" Brake.

Had the braking power as shown in the last column of the table and represented by the full-line curve, been 134 per cent. instead of 150 per cent., the two stops would have been the same.

the relative efficiency of the various forms of brakes for passenger trains, the difference in the length of the lines corresponding approximately to the reduction of distance required in which to stop a given train of one locomotive and six cars from a speed of 60 miles per hour since the introduction of the air-brake. If the diagram were inverted so that it is viewed upside down, a fair idea will be obtained of what the relation between the stops would have been through the respective periods of train development had there been no change in the air-brake since first applied.

The tendency of modern rolling stock to lower brake efficiency is further illustrated in Fig. 19. The retardation curves show the stopping distance from about the same initial speed of a train composed of cars weighing 30,000 pounds and braking at 83 per cent. and a train of 84,000 pounds cars braking at 150 per cent. It will be seen that notwithstanding the 60 per cent. greater braking power of the heavier train, the difference in stop is not greatly in its favor. The reason for this is clear when it is considered that the work done during the stop for the light train was 14.5 foot-tons per brake-shoe per second while with the heavy train it was 29 foot-tons per brake-shoe per second, which shows that under modern conditions each brake-shoe is doing about twice the amount of work required formerly in order to make approximately the same stop, which consequently lowered the coefficient of friction and thus tended to equalize the actual retarding forces developed in the two cases.

The diagram below the comparative curves shows, first, the length of stop for light train with the equipment of its day; second, what the stop would have been with the heavier train had there been no change in brake equipment to correspond to the increased weight of train; third, what braking power was actually required to stop the heavy train in the distance the light train was stopped with its brake equipment; and fourth, what the stop of the light train would be if it were possible to apply to it the brake equipment required for the heavy train. This is a significant and all-sufficient example of what is required to meet modern conditions as effectively as they were provided for in the past.

CONTROL VALVE EQUIPMENT.

With the introduction of heavy sleeping cars and passenger equipment cars carrying heavy motive power apparatus such as

self-contained motor cars, not only were the factors above mentioned, which tend to lower brake efficiency, aggravated to a marked degree, but limiting conditions were encountered in other directions. The brake force required to control such heavy (135,000 to 170,000 pound) cars with approximately the same effectiveness obtainable with the apparatus used on lighter cars became so great as to exceed the capacity of a single brake-cylinder even with the highest brake-cylinder pressure and greatest multiplication of its power by leverage that could be permitted.

The single brake-cylinder had already reached a maximum of 18 inches in diameter and it was generally agreed that a larger size brake-cylinder would be impracticable from a manufacturing, operative and maintenance stand-point.

With 100 to 105 pounds brake-cylinder pressure being obtained from 110 pounds brake-pipe pressure carried there was little hope of raising the cylinder pressure higher and no material or permanent improvement in the general condition would result even if the full 110 pounds could be realized in the brake-cylinders.

There was no suggestion of an increase in brake-pipe pressure above the present standard, it being universally recognized that 110 pounds was about as high as could safely and economically be used with the type of apparatus and fixtures in general service.

The multiplication of the brake-cylinder pressure through the leverage of the foundation brake rigging had been carried, in many cases, beyond the recommended 9 to 1 maximum simply because it was the most obvious, simplest, and most convenient means of providing the heaviest cars with a proportionate braking power approaching that used on lighter cars. The evils of this expedient soon became manifest in dragging brake-shoes, "slow release" and trouble in keeping the brake rigging properly adjusted. Most important of all, from a safety stand-point, was the effect of this high leverage ratio in multiplying the losses due to lost motion in the rigging or truck members, brake-shoe movement and so on, the result of which was evidenced in excessive false piston travel and consequent failure to obtain the maximum brake-cylinder pressure contemplated in the design, or still more serious loss in braking power due to the piston travelling so far as to bottom on the cylinder head.

These and other mechanical limitations therefore barred fur-

ther progress in this direction and two alternatives remained, viz.:

1. To increase the effectiveness of the single brake-cylinder as far as possible by using two brake-shoes per wheel (clasp brake).

2. To use two brake-cylinders per car.

While the first of these alternatives would undoubtedly be of some assistance, there are objections to this design, not the least of which is a reasonable doubt whether the acknowledged theoretical advantages of the clasp brake would prove to be practicable; and a reasonable certainty that no matter to what extent its theoretical advantages might be realized in practice, the maximum increase in efficiency thus afforded could not be sufficient to meet the demands of conditions already existing, to say nothing of the possibilities of the future.

On the other hand, the two-brake-cylinder proposition did not necessarily involve any new or untried principles, since two complete equipments of the type already in service might be used, one for each end of the car. This would provide ample stopping power for existing conditions and lend itself readily to extension, as still more severe demands might arise. It was therefore recognized that such an arrangement offered the best solution of the problem of the proper air-brake equipment for passenger cars weighing 130,000 pounds or over. Furthermore, it was seen that a single valve mechanism to control the admission of air to and release of air from the two-brake-cylinders would possess such marked advantages over a complete double equipment for each car as to make a satisfactory and practicable design of such a valve greatly to be desired. In reality, the success and scope of the two-cylinder arrangement depended wholly on the characteristics of the valve device adopted for this purpose.

It was but logical that, in the first practical solution of this problem, use was made of the same principles, both of construction and operation, as had been embodied in a valve device already in use for some years and giving the best of satisfaction under conditions quite similar to those of the two-cylinder passenger-car equipment. While this valve (the distributing valve of the "ET" locomotive brake equipment) was particularly designed to operate in connection with two or more brake-cylinders on locomotives, its distinctive operative features were equally advantageous for passenger car service. Consequently, when the in-

troduction of 85-ton multiple unit electric motor cars on the N. Y., N. H. & H. R. R. electric zone called for a correspondingly effective form of brake apparatus, of necessity using two-brake-cylinders, the valve mechanism adopted was a modification of the distributing valve type, the changes being only such as were required to adapt this device to passenger train service. From the start, its performance under the severe demands of suburban electric service was so satisfactory as to thoroughly establish the advantages of this type of equipment for the high braking efforts and large brake-cylinders required by the heavier classes of cars. It is hardly necessary, however, to go further into detail regarding its construction or operation, first, because the design of its operating mechanism resembles so closely that of the distributing valve, and, second, since it served to mark one stage only in the development of a distinct type of brake apparatus for such service.

As already stated, with the advent of passenger carrying cars weighing from 135,000 to 150,000 pounds in steam road service and still heavier motor cars, carrying extraordinary dead weight loads, the limit of an efficient single-cylinder equipment was approached and in some cases exceeded. But this was only one phase of the situation. The demand of high speed heavy train service had steadily advanced to a point where, for adequate control, something more was required of a brake than merely maximum retarding power in emergency. The ordinary service functions and automatic safety and protective features became hardly secondary in importance. Briefly stated, the requirements recognized as essential in a satisfactory brake for this modern service are as follows:

1. Automatic in action.

2. Efficiency not materially affected by unequal piston travel or brake-cylinder leakage.

3. Prompt serial service action.

4. Graduated release.

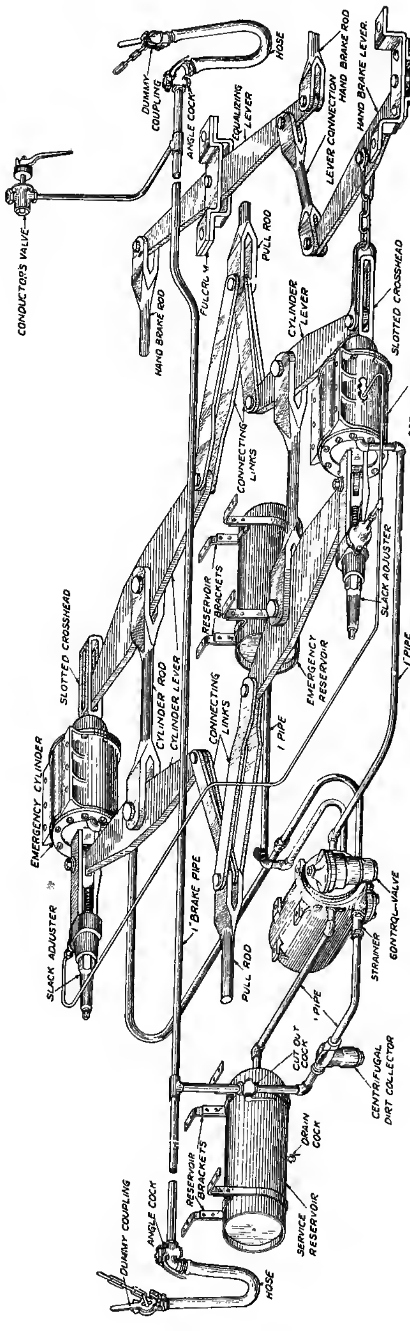
5. Quick recharge and consequent ready response of brakes to any brake-pipe reduction made at any time.

6. Predetermined and fixed flexibility for service operation.

7. Full emergency pressure obtainable at any time after a service application.

8. Full emergency pressure applied automatically after any

FIG. 20.



Improved brake equipment for heavy passenger cars; control valve equipment; schedule "PC".

predetermined brake-pipe reduction has been made after equalization.

9. Emergency braking power approximately 100 per cent. greater than the maximum obtainable in service applications.

10. Maximum brake-cylinder pressure obtained in the least possible time.

11. Maximum brake-cylinder pressure maintained throughout the stop.

12. Brake rigging designed for maximum efficiency.

13. Adaptability to all classes and conditions of service.

That certain of these requirements demanded radical changes in the valve device used on the car is evident from a comparison with the functions of the previous types already referred to, since but one of these required functions was contained in the older equipment. These considerations led to the latest development in the art of controlling heavy, high-speed passenger trains, employing what is known as a control valve in the place of a triple valve, the functions of which have already been mentioned in brief. The complete equipment is known as the schedule "PC" and is illustrated in Fig. 20.

The relative stopping power of the most efficient of the old order of brake apparatus—the High-Speed Brake—and of the control valve apparatus, is contrasted in the curves of Fig. 21. Both the comparative lengths of stop and the relative rates of rise and amount of maximum braking power are shown by the curves. It will be noted that the 575 foot shorter stop made with the "PC" equipment resulted not only from the higher braking power utilized but also from the quicker rate at which this braking power was built up to its maximum value. As a result you will note that the speed of the high-speed equipment train when passing the point (1100 foot stake) at which the "PC" equipment train stopped, was still as high as 38 miles per hour which means that 40 per cent. of its initial kinetic energy (at 60 miles per hour) still remained to be dissipated (harmlessly in this case, fortunately) before the train could be stopped.

Moreover, not only was this speed 38 miles per hour in the case of the high-speed equipment train, but it passed the 1100-foot stake 6 seconds before the "PC" equipment train reached that point. That is to say, the train with the "PC" equipment came to a stop at the 1100-foot stake 6 seconds after the train equipped

with the high-speed equipment passed this point at a speed of 38 miles per hour. At the time when the "PC" equipment train stopped at the 1100-foot stake, the train equipped with the high-speed brake equipment was 275 feet further on, and still running

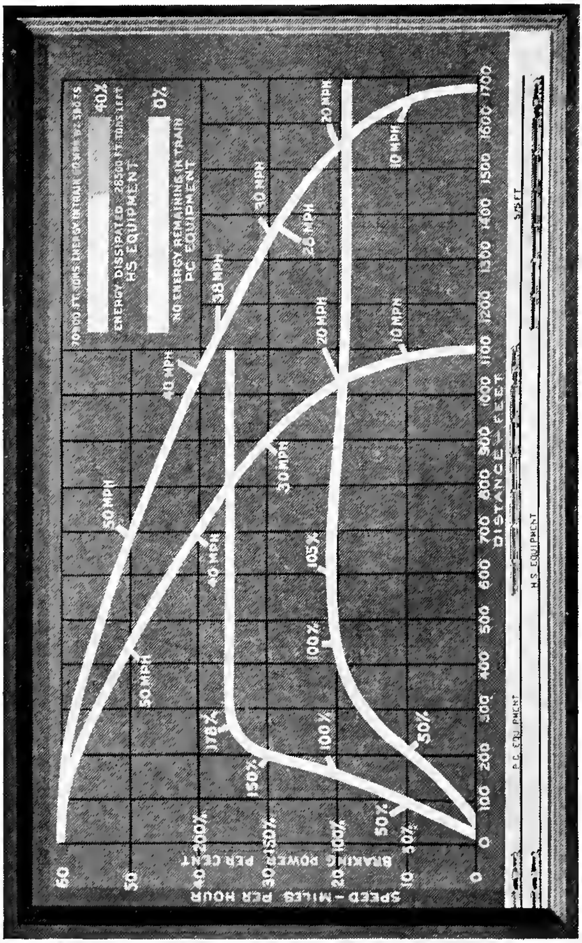


FIG. 21.

Comparative train stops, control valve and high-speed brake equipments.

at a speed of 28 miles per hour, which corresponds to a kinetic energy 22 per cent. of the original amount when the train was running at 60 miles per hour.

SUMMARY OF DEVELOPMENT IN PASSENGER BRAKES.

From what has gone before, it will be seen that the existence and development of the passenger brake devices which have been

described have come about, not spontaneously, of themselves, or solely for themselves, but in response to a definite need or for the purpose of accomplishing certain necessary and desired results, the end in view always being the safeguarding of life and property and increasing the facility, economy, and dispatch with which larger volumes of traffic can be handled.

Briefly, the conditions to be overcome and the objects to be attained may be summarized as follows:

CONDITIONS.—Increased weights of trains, greatly decreasing the relative efficiency of the brake and increasing the energy to be overcome in bringing the train to a standstill. Of two trains on the same number of wheels having the same nominal percentage of braking power, one being twice the weight of the other, the heavier train will run at least one-third further than the other.

Higher running speeds, increasing the energy to be overcome in making the stop in proportion to the square of the speed and adding directly to the length of stop according to the time required to obtain effective braking power on the train as a whole.

Greater frequency of trains, which increases the necessity for stopping quickly in a rapidly increasing ratio. Not only is it of more importance than ever that the trains be readily controlled within the distances between signals, but, with double- or four-track roads, there is the added greater possibility of the track on which the train is running being blocked by a break-in-two or other accident on the opposite track.

Increasing insistence upon the comfort and convenience of passengers and at the same time for greater economy in the handling of traffic, the latter being, in the nature of things, antagonistic to the former, without some special provision is made, looking to ultimate rather than circumstantial economy.

OBJECT OF IMPROVEMENTS.—*In Service Applications.*—(1) Much more flexible control of the train, greatly reducing possibility for shocks. (2) More uniform braking power, reducing surging in trains and flat wheels. (3) Uniform and maintained cylinder pressure notwithstanding variations in piston travel or leaky brake-cylinders. (4) Constantly recharged auxiliary reservoirs, which increase the safety to the highest degree. (5) Better protection against excessive braking power in service applications. (6) Shorter, smoother and more accurate stops.

In Emergency Applications.—(1) The human factor in the equation is reduced to a low point. (2) The increased per-

centage of braking power and prompt rise of brake-cylinder pressure compensates in a large degree for the decrease of the retarding force due to the increased work the brake-shoe now has to perform as compared with the old style brake. (3) Trains can be stopped in somewhere near the same distance as when the cars were lighter. (4) *Emergency Pressure is Available Even After a Service Application Has Been Made to an Extent Never Before Attained.*

EMPTY AND LOAD BRAKES.

Under modern freight-traffic conditions, as already stated, uniformity of retardation on all cars in a train is second in importance only to safety. This, with mixed loads and empties hauled in the same train, is inherently unobtainable with the type of brake considered thus far. It can only be accomplished by providing means whereby a relative braking force more nearly comparable to that of the empty car can be utilized on the partially or fully loaded car.

The difference in braking power with the standard brake on loaded and empty cars would no doubt astonish anyone unfamiliar with the facts, but can be appreciated from the statement that the same brake-cylinder pressure which gives 60 per cent. braking power on an empty car will give only from 17 per cent. to 20 per cent. when this same car is loaded to its full capacity.

Four possible solutions are evident:

1. *Increased Brake-cylinder Pressure for a Given Reduction and on Equalization.*—In order to leave the braking power on the empties the same as at present but increase that on the loaded car to the desired amount, it would not be permissible to increase the brake-pipe pressure above the 70 pounds at present generally used. Even if an increase above 70 pounds *for this purpose* were permissible, it would not give any higher braking power for ordinary service reductions, but only afford a higher equalization pressure. An increase of reservoir volume, on the loaded car is therefore another alternative. The maximum increase in pressure then available could not be greater than 70 pounds which, while only increasing the braking power on the loaded car by 40 per cent. (that is, from, say, 20 per cent. to 28 per cent. braking power) at the most, would destroy many fundamental and necessary features of the brake. This is only about one-fifth or one-sixth of the increase required for a proper control of a car loaded

to from two to four times its light weight. This method is therefore impracticable.

2. *Increase the Total Leverage Ratio Temporarily on the Loaded Car.*—In the first place, the total leverage ratio for the heavier modern freight cars and standard equipment is already so high that any such increase as required by the loaded car would be prohibitive. Aside from this, however, it has been demonstrated by many repeated but futile attempts that none of the various schemes thus far proposed for mechanically changing the leverage to correspond with the increase in car lading (whether automatically with an increase of car weight or manually) can be made practicable for actual road service. Once established for the light car, the same leverage ratio must be utilized for the loaded car.

3. *A combination of increased leverage ratio and auxiliary reservoir volume* might be suggested as a possibility but it would evidently combine the objectionable features of the first and second alternatives just mentioned in such a manner as to aggravate the undesirable effects of each. This method, therefore, fails to afford the relief sought.

A fourth possibility remains, viz.:

4. *A Second Brake-cylinder to be Added to the Ordinary Brake-cylinder to Control the Load.*—A number of equipments of this type, of varying form, are being successfully operated on a number of railroads, particularly in mountain grade service, where the additional braking power thus provided is of advantage in increasing the amount of tonnage handled in a given time down the grade. It will be of interest to state, in outline only, the characteristic features of forms which have proven successful.

1. Two brake-cylinders per car are used, one for the empty car and both used together when the car is loaded to say two-thirds or more of its rated capacity.

2. Standard leverage arrangement for the "empty" brake-cylinder.

3. Suitable connections, take-up mechanism, levers, etc., to form the connection and required multiplication of power from the additional "load" cylinder to the "empty" cylinder lever system.

4. Valve mechanism, in addition to that required by the "empty" brake, for controlling the supply of air to and from the added or "load" brake-cylinder.

5. Semi-automatic change-over valve-mechanism for cutting the "load" brake in or out either manually or under certain circumstances, automatically.

6. Additional reservoir capacity to furnish the air supply for the "load" brake.

The important problems entering into the operation of brakes on freight trains under present-day intensive traffic duty, for which the "empty and load" type of apparatus offers an ideal solution may be briefly stated as follows:

1. The necessity for more braking power on loaded cars than afforded by the ordinary form of brake, in order to increase the tonnage which can be handled down long or heavy grades with safety. Locomotives of such power are now built, that it is possible, in some localities, to haul heavier trains to the top of the grades than can be safely controlled down the other side with the standard brake.

2. Trains of mixed loads and empties, especially long (50 to 100 cars) trains, where it is physically impossible or economically impracticable to arrange the empty and loaded cars in the train to the best advantage, thus adding greatly to the danger of the train parting or damage to the lading and equipment due to inequality of braking power in different parts of the train, when the brake is applied at some critical speed or locality.

3. Locomotives of great weight, but relatively low braking power, tending to increase the internal stresses in the train due to unequal retardation on diffrent cars in the train.

4. The advent of large capacity cars, aggravating the differences in retardation due to lading, so that the percentage of braking power on such cars, when loaded, is reduced to a greater extent than on cars of lower capacity, for which the proportion of loaded to light weight is less.

5. The requirement of operating both short and long freight trains with practically all air-brakes cut in. This, on a long train, with loads ahead and empties on the rear end, presents an operating problem difficult of solution with the old standard brake.

PRINCIPLES OF TRAIN BRAKING AND BRAKE DESIGN.

Throughout the foregoing description of the development of the various types of brake apparatus, occasion has been taken to explain at the same time the operating conditions and service requirements responsible for their being. While this has neces-

sarily involved some reference to some of the fundamental principles underlying the proper application and operation of brakes as related to convenience, economy and safety in train control, there are certain limiting conditions and fixed laws which should be treated more specifically and in detail. This is not so much because the present state of the air-brake art exemplifies the application of these laws and principles to the complex demands of modern freight and passenger service, but rather because it is only by a careful study and sound working knowledge and appreciation of the significance of these laws that anyone is able to judge positively and accurately, on the one hand, the adaptability of, or necessity for, any new air-brake device, and on the other, what are the requirements to which any new device or method must conform in order to adequately and efficiently satisfy the requirements of new service conditions.

STARTING AND STOPPING.

The problems of deceleration, retardation and the flexible control of trains must receive more and more attention from a scientific and technical stand-point, in order that to-day theory and practice may be combined to produce the best results in the shortest time. This is necessary if the brake is to efficiently and satisfactorily meet the wonderfully changed conditions which have developed since the invention of the quick action, automatic brake. The high speeds and great weights of the present day requiring that advantage be taken of every opportunity offered to increase and flexibly control braking power.

Starting and stopping of trains are complementary factors in the problem of making time between stations, therefore it is evident that the best results can only be obtained where both factors are given due consideration. Generally, the starting factor is the only one fully considered, or, at least, the one more fully provided for, and this notwithstanding that better results can be obtained if both are considered and the more efficient brake system installed.

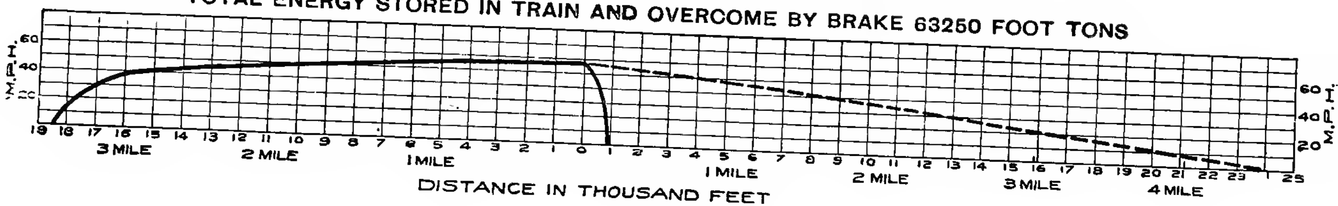
In another sense, the question of stopping is the most important, as the safety of the service and the freedom of delays to a great degree depend upon it. The measure of the value of the brake is two-fold,—(1) the ability to stop in the shortest possible distance when necessary; and, (2) to permit short, smooth and accurate stops being made in regular operation. Therefore both these factors should be considered when design is under way.

FIG. 22.

CLASS E-2-D LOCOMOTIVE.

TOTAL WEIGHT OF TRAIN	559.6 TONS.
ACCELERATION	DISTANCE OF 18500 FEET
TIME OF ACCELERATION	5 MIN. 47 SEC.
DECELERATION	DISTANCE OF 954 FEET.
TIME OF DECELERATION	18.7 SEC.

TOTAL ENERGY STORED IN TRAIN AND OVERCOME BY BRAKE 63250 FOOT TONS



BROKEN LINE REPRESENTS STOP WITHOUT THE USE OF BRAKES.

NOTE:-
THE CALCULATED STOP WITHOUT BRAKES WAS OBTAINED BY ASSUMING 9.6 POUNDS PER TON RETARDATION DUE TO WIND RESISTANCE AND JOURNAL FRICTION. TRACK LEVEL.

Acceleration and deceleration curves; Absecon tests.

Unfortunately, the brake is usually looked upon as a safety device only, and it is because of the prevalence of this idea that its installation and maintenance do not receive the consideration merited. Considering the investment, there is no part of the railway equipment that will give greater material returns than the brake when properly installed, operated and maintained. If the brake could to some extent be separated from the idea or impression that it is a safety device only and proof advanced to show that it makes possible the hauling of heavier cars,—in fact, makes the heavy car possible,—that it makes possible, faster and more frequent service,—as much or more than does the locomotive, the block signal and the good roadbed,—and that, if given the consideration it should have, it would increase the possibilities, profits and value of all these things,—its importance would be more fully appreciated and, therefore, at least the same consideration be given to its design and installation that is accorded to other parts of railway equipment. A safety device, the brake is, par excellence; but it has other reasons for its existence.

Very few, perhaps, realize that the brake under a single car is much more powerful than the locomotive that pulls the train, yet this will be apparent to any who examines the records of a dynamometer car alone attached to an engine, the stops being made by brakes on the dynamometer car. Few realize that it takes a locomotive perhaps five minutes, perhaps ten minutes, and a distance of some miles,—six or seven,—to attain a speed of sixty miles per hour. Imagine the condition of affairs which would exist if it took a brake that length of time and distance to stop the train. The comparison is somewhat startling, but it is only because the condition is one of those commonplaces which have been taken for granted so long that they are accepted as inherent rather than being given the degree of consideration which their significance warrants. Fig. 22 is an illustration of the facts stated, taken from the records of a run during a series of tests at Absecon, N. J., 1907, the train being composed of a locomotive and ten cars. What it took the locomotive nearly six minutes and a distance of about three and a half miles to accomplish was overcome by the brakes in less than twenty seconds and within a distance of about one thousand feet. The broken line represents what the stop might have been if no brakes had been used, *i.e.*, the train brought to rest by the resistance of the air, and

journal friction. All of the elements so strongly contrasted in Fig. 22 are familiar in themselves but their reciprocal relationship is often overlooked. The average passenger train of to-day can be stopped from a speed of sixty miles per hour in about twenty seconds' time. To build a steam locomotive that would accelerate a train in the time and distance that the brake stops it, would be impossible, for in order to have the necessary adhesion to the rails, which would permit of developing the required drawbar pull, the steam locomotive would have to weigh approximately twice as much as the train itself, which is, of course, prohibitive. Electric locomotives, however, are no longer to be regarded with uncertainty or as mere experiments and there is every reason to believe that the electric locomotive will be able to accelerate a train to a speed of sixty miles an hour in certainly not more than a minute and a half, and probably not more than one minute's time. That means that the brake is going to be even *more* important in the future than it has been in the past. In proportion as we accelerate, we must perforce be prepared to decelerate. The ability to accelerate, or even to run at high speeds, must be measured by the ability to stop.

As an example, however, of how little this is appreciated such a question as the following is often asked and a categorical answer apparently expected: "In what distance should a train be stopped from a speed of fifty miles per hour?" Perfectly simple, isn't it? Here we have one known factor, from which we are expected, apparently, to derive all the other factors which are of equal importance and must be known before an answer of any value can be given to such a question. A few of these factors are: the light weights and loads of the vehicles composing the train; the percentage of braking power used with engine and cars; whether or not all wheels, including truck and trailer (if any), of the locomotive were braked; what type of brake equipment was used; what pressures were carried; whether the train was accelerating or decelerating; on a curved or straight track; on an ascending or descending grade, or level; the condition of the rail; whether the brakes were applied in service or emergency, or ordinary service and then emergency; the piston travel on each vehicle: the losses to friction of parts, brake-beam release springs, etc.; wind resistance; quality and thickness of brake shoes and method of hanging them, for this affects materially the efficiency of the brake, both as to absorbing power and lengthen-

ing the piston travel which reduces the pressure otherwise obtainable. Furthermore, it should by no means be understood that the precise effect of each of these could be accurately calculated, even though full information were at hand, and a little thought will make it evident that each of the factors mentioned above may have a considerable influence on the length of the stop.

These things are merely mentioned to emphasize the great importance of the air-brake and the necessity for considering carefully what principles govern its action. It does not make very much noise. It does not occupy so prominent a place in the papers as electricity, for instance; yet it has been much more of a factor in railroad development up to the present time than electricity.

I may be pardoned for asking you to form a comparison between the propelling and stopping mechanism of our steam railroads. The locomotive is much in evidence, being large and of powerful appearance and placed in the most conspicuous place in the train. The brake is, outwardly, a comparatively insignificant piece of apparatus, installed on the different vehicles of the train; placed underneath the cars where it is hard to find, and seldom observed by the traveller. The very fact that it is so distributed over the train is one reason for its power and efficiency. When we realize the forces handled by the two devices, and the great difference in point of time in which their work is accomplished, our respect for the brake will be stimulated, since it *must* be capable of dissipating the energy, stored by the locomotive in the train, in but a fraction of the time required by the locomotive to do this, if the safety of transportation is to be preserved.

FUNDAMENTAL PRINCIPLES IN BRAKE DESIGN.

In the establishment of a logical basis of brake design, applicable to the conditions under which brakes in general must operate and involving a determination of the essential elements of an elementary brake system for any given car, the starting point must be the light weight of the car. Fortunately this can usually be determined in advance to any desired degree of accuracy. For convenience, suppose the car to be fully equipped with a complete brake equipment and by an analysis of the factors involved in stopping the car, determine how these factors may best be provided for in the design.

Assuming that the wheels do not skid, the actual *braking force* acting on a car when the brakes are applied is the force of the friction between the brake-shoes and the wheels, tending to retard the rotation of the wheels and thus stop the car. The relation which this bears to the energy stored up in the moving car, provided the "adhesion" of the wheel to the rail is not exceeded, determines the effectiveness of the brake and the length and time of stop. The energy of the moving car consists of two parts—that of the car as a whole due to the velocity of translation, and that of the revolving wheels, due to their rotation, and varies as the weight of the car and as the square of its velocity.

The latter may roughly be taken as 5 per cent. of the energy of translation for 12-wheel cars and as 2 per cent. of the energy of translation for 8-wheel cars. In ordinary calculations, however, this factor is usually neglected, and properly so, because for modern rolling stock the resistances other than as derived from the brakes, such as internal friction, air resistances, flange friction and so on, has been shown by actual experiment to at least equal if not exceed the inertia effect of the revolving parts. Consequently a greater error is made by considering the energy of rotation without at the same time taking into account the resistances to motion which exist due to other causes than the brake-shoes (which, it should be noted, are usually indeterminate and subject to considerable variation) than to assume that these two opposing factors neutralize each other.

The frictional force between the brake-shoes and wheels depends on the pressure acting on the shoes and the coefficient of friction between the shoes and the wheels. In making a stop, therefore (it being assumed throughout that the wheels do not skid), the factors involved, so far as retarding the rotation of the wheels is concerned, are:

1. The total amount of brake-shoe pressure in pounds, commonly called the "braking power."

2. Coefficient of friction between the shoes and the wheels, by which the brake-shoe pressure must be multiplied in order to determine the actual retarding force.

3. The weight resting on the wheels.

4. The velocity of the car.

5. The rotative energy of the wheels.

Only one of these factors can be controlled even partially in service or fixed arbitrarily in designing the brake system, viz.,

the pressure on the brake-shoes. Inasmuch as the wheels must not skid when the weight resting on the wheels is least,—that is, when the car is not loaded,—the light weight of the car must be taken as the basis of calculation regarding brake-shoe pressure, except in the case of some form of "empty and load" brake. Since the "braking power" is, by custom, measured by a scale of percentages wherein 100 per cent. represents a shoe pressure on each wheel equal to that wheel's pressure on the rail, the problem is then to determine and insure the obtaining of the proper relation between the brake-shoe pressure and the light weight of the car.

As pointed out above, the factors involved, such as frictional coefficients, speed, weights, etc., are so subject to variation in service that no theoretical conditions can determine the proper nominal percentage braking power (*i.e.*, the ratio of brake-shoe pressure to light weight of car), which shall best meet average road conditions. This can be fixed only by experiment and experience and is subject to modifications as conditions change or become more thoroughly understood. For example, many years' experience has proven that 90 per cent. braking power for passenger cars gives satisfactory braking effects with a reasonable margin against wheel sliding and sufficient power for service stops. This was determined by the results obtained on the lightest cars. So far as wheel sliding is concerned, a 150,000-pound car braked at 95½ per cent. has practically the same margin against wheel sliding as a 70,000-pound car braked at 90 per cent. But if the percentage of braking power is varied, the uniformity of service braking effect, other factors being the same, is lost. *Therefore, the percentage of braking power determined as a satisfactory maximum for the lightest cars* must be adhered to on all cars, in order to bring about as nearly as possible the uniform results which are necessary for satisfactory service operation.

Having, therefore, chosen a certain percentage of braking power which should be obtained on all cars, it is evident that what actually is obtained, in any given instance, depends on the total leverage ratio and the pressure per square inch on the brake-piston. It will be apparent that all resistances between the brake-piston and brake-shoes, such as release springs, reactions of hanger links, friction of rigging, etc., must necessarily be ignored until the essential factors in the design are determined upon.

The total leverage ratio is fixed within certain limits by purely mechanical consideration, with regard to piston travel, shoe

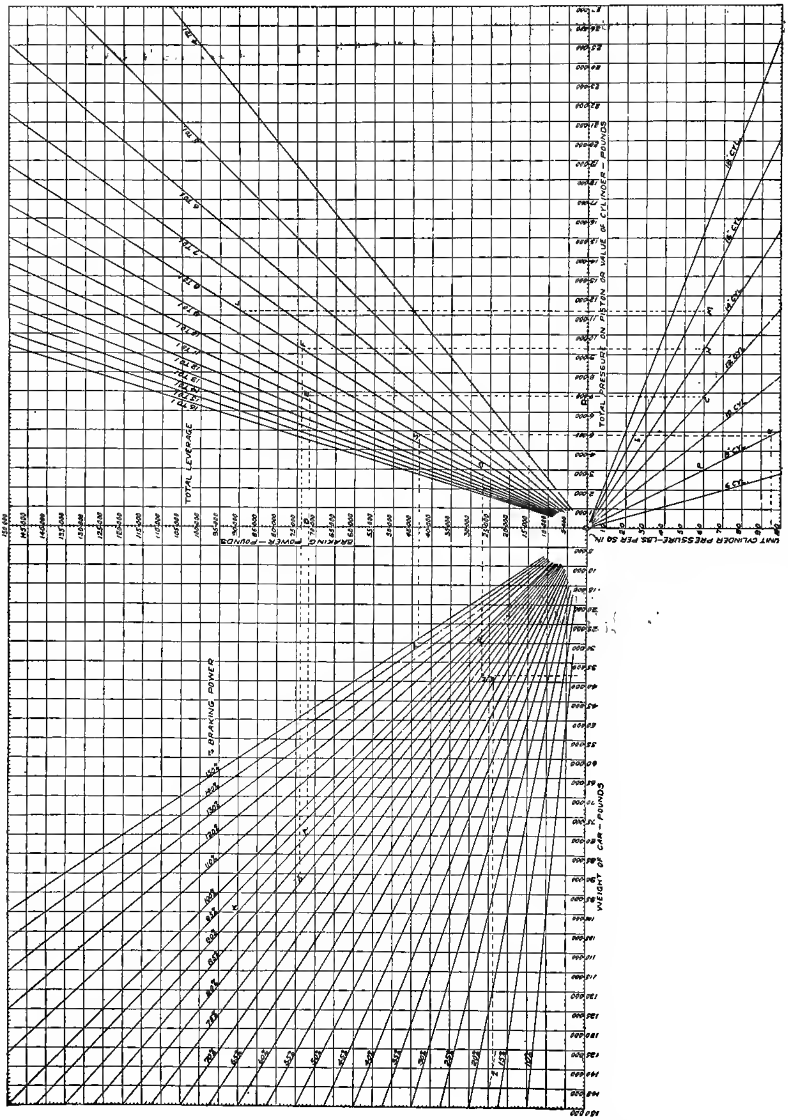


FIG. 23.

Chart showing relation between size of brake-cylinder, brake-cylinder pressure, total leverage ratio, braking power, and weight of car.

clearances, etc., and once the foundation brake rigging is designed, remains always the same.

Hence in any given case the percentage of braking power actually obtained depends entirely on the pressure existing in the brake-cylinder, which varies in practice from zero to the maximum obtained when an emergency application is made.

In designing the brake system for a car, therefore, the leverage ratio and size of brake-cylinder must be so proportioned as to give the required braking power in pounds, with some arbitrarily chosen pressure in the brake-cylinder. Evidently this braking power will be obtained in practice when the brake-cylinder pressure is that on which the design of the brake system was based. For any pressure lower or higher than this, the braking power, in pounds, will be correspondingly lower or higher than the nominal. Furthermore, the actual percentage of braking power (ratio of brake-shoe pressure to weight on wheels) varies not only with the brake-cylinder pressure but also with the condition of the car,—whether loaded or empty.

From a consideration of these conditions it seems evident that it is practically impossible to provide for even an approximate uniformity of brake action on different cars in service by any method of design. The best that can be done is to establish and adhere strictly to the assumed standards upon which such designs are based.

1. The "percentage of braking power" in terms of the light weight of the car.

2. The brake-cylinder pressure upon which this percentage is based.

The former, as has already been stated, must be determined from experiment and experience. The latter must be chosen arbitrarily, but it should have the same value for all brake calculations, in order to insure a common base being universally used and understood. Fig. 23 graphically illustrates the relations existing between these two factors for different weights of cars and total leverage ratios. The question now is, therefore, "What brake-cylinder pressure should be used as a basis in designing the brake systems of all types and classes of cars?"

With a given auxiliary reservoir charged to a standard pressure, and with a given brake-cylinder having standard piston travel, a certain definite pressure of equalization is obtained, which is constant so long as the other factors involved are kept constant.

When an emergency application is made, since a portion of

the air in the brake-pipe or other source of supply is used in addition to that in the auxiliary reservoir, the resulting brake-cylinder pressure is augmented in proportion, and a higher maximum pressure therefore obtained. Evidently its value must depend upon the relation which the supplementary brake-pipe volume bears to that of the auxiliary reservoir and brake-cylinder combined. With equipments now in general use this ratio must necessarily decrease as the size of the car increases because the brake-pipe volume remains practically constant for all sizes of cars, while the brake-cylinder and auxiliary reservoir volumes increase as the size of the car increases. It then follows that where air from the brake-pipe alone is used to augment the brake-cylinder pressure in emergency applications, the emergency pressure thus obtained must vary with the different combinations of auxiliary reservoir and brake-cylinder necessary for different sizes of cars—the gain in pressure from this source over that obtained in full service equalization being greatest with the smallest sizes of auxiliary reservoirs and brake-cylinders.

Hence, in choosing a brake-cylinder pressure on which to base brake calculations, that obtained in emergency, which was satisfactory where the brake-cylinders were of such size that a uniform pressure was obtained in both service and emergency, is now excluded at the outset,—from the stand-point of uniformity,—since in the nature of the case it is not uniform for all weights of cars. This is for the reason that brake-cylinders may vary from 6 inches to 18 inches diameter with correspondingly varying pressures in emergency. And if the braking power desired is based on a brake-cylinder pressure higher than can actually be obtained, then for lower cylinder pressures the brake is not so effective as it might be made, were the braking power based on the pressure actually obtained. The smaller cars which do obtain this pressure, give the calculated braking power in emergency, but the heavier cars cannot, and there is a loss, both in uniformity of emergency action and possible efficiency.

On the other hand, for brake-pipe reductions less than sufficient to produce equalization, the cylinder pressures obtained are uniform, provided the other factors are uniform in value and the pressure at which the auxiliary reservoir and brake-cylinder equalize is supposed to be the same for all combinations of reservoirs and cylinders, with the same initial pressure. To obtain this uniformity it is only necessary to properly proportion the

reservoir volume to the brake-cylinder volume for some standard piston travel. We then have a pressure base which will be constant when the other factors involved have their proper or standard values. It would seem that this is the basis to which all braking power calculations should be referred, for the reason that it is the nearest approach to a uniform and constant pressure obtainable under the wide range of conditions governing this choice. This adds to the standard enumerated on the preceding page, the following:

3. This brake-cylinder pressure must be the equalized pressure on the auxiliary reservoir and brake cylinder.

4. A predetermined ratio between auxiliary reservoir volume and brake-cylinder volume to produce this equalization must be adhered to.

The fundamental steps in designing a brake system for any given car may now be outlined as follows:

Given the light weight of the car the proper braking power per cent. has been established from results of experiment and experience and this enables the total brake-shoe pressure to be calculated.

Mechanical considerations fix the total leverage ratio between certain limits, the maximum and minimum values of which enable a maximum and minimum total brake-piston pressure to be calculated from the preceding.

This total brake-piston pressure depends upon the size cylinder and pressure per square inch used as a basis. The pressure basis to be used should be that agreed upon as a universal standard, for such calculations as this, and, as has already been pointed out, uniformity requires that the *equalization pressure* (50 pounds per square inch), from the lowest standard brake-pipe pressure carried, should be the base chosen.

Having determined the unit pressure, the size of cylinder can be chosen from the standard sizes manufactured to give the desired braking power with a total leverage within the maximum and minimum limits as defined above.

To obtain the desired 50 pounds equalization pressure from the standard 70 pounds brake-pipe pressure with a standard piston travel, is simply a matter of correctly proportioning the auxiliary reservoir volume to that of the brake-cylinder at the piston travel employed as standard.

We then have an auxiliary reservoir which, at 70 pounds in-

itial pressure, will equalize with its brake-cylinder, when this has eight inches piston travel, at 50 pounds, and the brake-cylinder piston is of such an area that the total pressure thus obtained, when multiplied by the total leverage, will give a total brake-shoe pressure equal to the desired percentage of the light weight of the car.

To be sure, in an emergency application, the braking power on all cars will be greater than that used in the design, and the lighter the car the greater the variation between service and emergency braking powers. But such non-uniformity in actual service is bound to obtain, and always has, since an increase to 90 pounds brake-pipe pressure, or a variation in piston travel produces similar results, to say nothing of losses due to leakage, resistances and variations in frictional coefficients. The advantage gained, however, by the method of design outlined is, therefore, in the fixing of a uniform and actually obtainable brake-cylinder pressure, which is necessary for service operations and is one of the most important factors in the calculation to be made.

It may be said in passing that with the more recent types of brake-equipments for passenger service, using a supplementary reservoir volume, in addition to that of a brake-pipe to produce high emergency brake-cylinder pressure, the size of supplementary reservoir used is calculated to give practically uniform brake-cylinder pressures in emergency applications with *all* sizes of brake-cylinders, thus taking advantage of the principle of high pressures for emergency stops and at the same time conforming to the principles of uniformity laid down above, it being a fundamental principle of modern brake design to keep the service equalization brake-cylinder pressure comparatively low, for reasons fully explained elsewhere, and use as high an emergency equalization pressure (as large a supplementary reservoir), as may be desirable.

In the attempt to secure a high emergency brake-cylinder pressure without the aid of the supplementary reservoirs referred to above, the relationship between brake-cylinder and auxiliary reservoir volumes existing in the *original* brake design was gradually lost; the auxiliary reservoir volume being increased slightly, from time to time, as heavier cars, requiring larger brake-cylinders, were equipped. On the lighter equipment the variations thus introduced were relatively unimportant, but in the case of heavy cars, requiring the 16-inch and 18-inch cylinders, it was im-

possible to increase the auxiliary reservoir volume sufficiently to obtain the desired emergency pressure, without at the same time interfering to a marked degree with the proper operation of the equipment in service. Consequently, a compromise was made, so as to obtain as high an emergency cylinder pressure as possible without increasing the service equalization pressure to an extent inconsistent with the proper normal functions of the brake.

By the aid of a supplementary reservoir volume, however, reserved during service operation, but available in emergency applications of the brake, it is now possible to obtain the required increase in stopping power for emergencies and at the same time return to the original volume relationship, the correctness of which has been established by long experience.

These relationships are determined by the following principles, which will be recognized at once as having been followed in even the earliest automatic-brake designs.

(A) For any given arrangement of leverage between the brake-cylinder piston, and the brake-shoes, the "braking power" is directly proportionate to the gage pressure of air produced in the brake-cylinder.

(B) The limitation of the maximum allowable pressure of air in the brake-pipe limits thereto the available pressure in the auxiliary reservoirs.

(C) With this fixed maximum charge in the auxiliary reservoir, the highest pressure obtainable in the brake-cylinder from this single source is that at which the air pressure equalizes between the two. This (absolute) pressure, therefore, equals the product of the initial absolute pressure in, and the volume of the auxiliary reservoir divided by the sum of, the volumes of the auxiliary reservoir and of the brake-cylinder (neglecting all clearance volume, temperature effect, etc.), and the "braking power" is as the corresponding gage pressure.

(D). This pressure of equalization should be limited because its height determines the range of those differences between final auxiliary reservoir pressure and initial brake-pipe pressure, which range affords the control of "braking power" applied.

(E) That while low pressure of equalization limits "full service" pressure, yet small range precludes nicety of control, especially as from the range there must be deducted such initial differences of pressure as are necessary to overcome the inertia and friction of the triple valve parts.

(F) That to afford heightened brake-cylinder pressure for use in emergency another quantity of air is necessary, and if this be, as in all past practice, that contained in the brake-pipe, the resulting absolute pressure will be equal, theoretically, to the maximum absolute brake-pipe pressure multiplied by the volume of the auxiliary reservoir plus the amount of air, in cubic-inch-pounds, obtained from the brake-pipe, this sum then divided by the volume of the auxiliary reservoir plus that of the brake-cylinder, so that the measure of the resulting braking pressure is the gage pressure corresponding to this resulting (absolute) pressure.

Now, it is the interdependence and reactive results of these simple and recognized principles in their combinations together with a corresponding proportioning of leverage between the brake-cylinder piston and the brake-shoes that determine the relative efficiency of a brake design.

From (F) it is seen that if other parts be enlarged the volume of the break-pipe, which is practically the same on all cars, becomes relatively small and the emergency pressure sought is so insufficient that in the equipments for heavy rolling stock resort has been had to enlarged auxiliary reservoirs with a correspondingly heightening of the "full service" pressure (C), and a resulting lessening of the range of control (D).

Again when (C) is heightened while (D) is lowered, the results of the lighter brake-pipe reductions cause magnified effects in the service braking, so that, when it is realized that such range as is possible is lessened by the lack of sensitiveness of the triple valve (E), there is likelihood of roughness of service stops.

Such being the case, it is apparent:

1. That there is a ratio of volume of auxiliary reservoir to that of brake-cylinder that should not be exceeded.

2. That such service pressures as result in the brake-cylinder should be made sufficient by a corresponding proportioning of the leverage.

3. That the volume of each car's part of the brake-pipe should be supplemented by proper means so as to afford the required braking pressure in emergency.

Starting, therefore, with a brake-cylinder of the size *dictated* by the vehicle to be equipped, as already explained, and by a proportioning of the leverage which shall accord with the service required, and assuming that

C equals volume of brake-cylinder, in cubic inches;
P equals service equalization pressure, in absolute units;
R equals volume of auxiliary reservoir, in cubic inches;
a equals absolute initial pressure in the auxiliary reservoir;
r equals permissible range of brake-pipe reductions;

it follows first, from the above definitions, that

$$r = a - P$$

and from (C) above, neglecting clearance volumes:

$$\frac{a \times R}{R + C} = P$$

from which

$$R = \frac{P}{a - P} \times C$$

$$= \frac{P}{r} \times C$$

which may be expressed in the following law:

The proper auxiliary reservoir volume, according to the principles laid down above, is equal to the volume of the brake cylinder determined upon multiplied by the ratio of the service equalization pressure fixed upon as standard to the permissible range of brake-pipe reductions.

Assuming, as in current practice, that P equals 50 pounds per square inch (gage) and a equals 70 pounds per square inch (gage), then we have

$$r = a - P = 20 \text{ pounds,}$$

and

$$R = \frac{P}{r} \times C$$

$$= \frac{65}{20} \times C$$

$$= 3\tfrac{1}{4} \times C.$$

That is, the volume of the auxiliary reservoir should be three and a quarter times the volume of the brake-cylinder. It is plain, however, that the effect of the clearance volumes, leakages, temperature, and other adverse influence will be such that to obtain the desired results in actual service a somewhat higher auxiliary reservoir volume must be used than that found by the above calculations. For example, with the standard 8-inch equipment, an auxiliary reservoir volume of 1620 cubic inches is used, which is about three and one-half times the brake-cylinder volume.

In determining the proper size of supplementary reservoir

(F) to be used a similar reasoning may be used. In addition to the symbols already defined, let

$S =$ volume of supplementary reservoir in cubic inches.
$E =$ absolute emergency equalization pressure.

Assuming for the purposes of calculation that the emergency pressure is the result of the equalization of the brake-cylinder, auxiliary reservoir and supplementary reservoir volume, it follows that

$$\frac{a\,(R+S)}{R+S+C} = E,$$

whence, by proper substitution and reduction, is derived

$$S = \frac{a\,(E-P)}{r\,(a-E)} \times C.$$

While the above expression is interesting as showing the simple relation which exists between the various volumes involved in the typical equipment as we have assumed it, it must be clearly understood, first, that all the additional air supply in emergency is supposed to come from the supplementary reservoir, having taken no account of that vented from the brake-pipe; and second, that in any actual installation similar to that discussed, the equalization is dependent upon the movement of certain valves actuated by spring and air pressures in combination, the resultant effect of which is such that in the actual working equipment the state of affairs is by no means as simple as has been assumed for the typical equipment. Instead of equalization taking place between all the volumes concerned simultaneously, there are time limitations imposed on the rate of flow from the various sources of air supply to the brake-cylinder, so as to derive the maximum possible benefit from the compressed air stored in each. There is also a material modification of these calculated results, due to the processes not being truly isothermal, as assumed, and so on. Proper allowance being made for these limitations, a formula might be derived, in the same manner as above, to completely cover the more complicated conditions, but as only the principles involved are now being considered it is unnecessary to go further into details, particularly as these are accurately determined by experiment.

In the above analysis, as is necessarily the case with all theoretical considerations relative to mechanical apparatus of this character, certain assumptions were made to furnish a basis from which to start. Hence, it should always be remembered that the

formulæ derived must be interpreted, for any given case, in the light of the modification of these primary assumptions which the nature of the installation or the character of the apparatus used, may involve. With this understanding, the above reasoning affords a logical and sound theoretical basis, not only for determining the correct proportions of new types of equipment, but also establishes a criterion, by means of which the shortcomings of incorrectly designed installations may be discovered.

BRAKES FOR ELECTRIC TRACTION SERVICE.

It would hardly be proper to conclude without mentioning the fact that the electric traction service has required even more specialized apparatus than that already mentioned in connection with steam-road service on account of the great variety of conditions under which electric cars operate from the single city street car up to the 8- and 10-car subway and elevated trains, to say nothing of the electric locomotive and multiple unit train service on electric division or steam railroads. It can easily be appreciated that these phases of the subject are of even greater magnitude and requires a greater variety of apparatus and complexity of detail than in the case of steam-railroad service. Consequently, no more can be said at this time than to simply state the fact that the multiplicity of requirements has been anticipated and provided for to the extent that the high standard of efficiency already outlined to you has been maintained without any compromise or failure to meet the requirements of the service. In one particular, at least, the highest type of brakes, for electric service, namely, the Electro-Pneumatic System, affords superior stopping power and service efficiency, since its electric transmission of quick action insures simultaneously and almost instantaneously maximum braking power on all cars in the train, while for service braking, it possesses the maximum flexibility of control, possible only in an electrically actuated brake system. This brake therefore possesses superior features which are particularly noteworthy whether they are considered from the stand-point of the time saved, the increased traffic made possible, or the safety insured. At the present time, this type of equipment appears to be the acme of the braking art, but as past experience has always shown, the same time which brings about changes in operating conditions is also sure to develop new and more efficient means for meeting new requirements.